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PRACTICAL ALLOYING

A Compendium of alloys and
processes for brass founders,
metal workers and engineers.

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By John F. Buchanan

Author of
Brass Founders' Alloys
and
Foundry Nomenclature

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PREFACE

THE progress made in the production of alloys within the last two decades has been phenomenal. There is no end to the invention of new alloys, and the number of variations in the composition of alloys that have long ago passed the experimental stages, is simply overwhelming. Out of the multitudinous mixtures advocated and employed in the practical and constructive arts, it is no easy matter to select, or even to classify the metals of importance.

The "battle of the bronzes" has been going on for at least thirty years, and the honors have fallen to phosphor bronze, aluminum bronze and manganese bronze at different periods. In other branches of the metal industry similar progress is being recorded. New alloys are being introduced or new additions are being made to old alloys, and new records are being made in alloy practice. It is needless to add that new difficulties are also presenting themselves, and these are the things that make effort worth while.

This book professes to be no more than a handy guide to the practical alloys and processes. The bulk of the matter originally appeared in *"The Foundry"* and other trade magazines, and judging by the number of inquiries addressed to me on many of the subjects treated, the reappearance of the articles in book form should be hailed with interest.

J. F. BUCHANAN.

PRACTICAL ALLOYING

I

METAL REFINING—ANCIENT AND MODERN

TO the average individual, the universe is a mass of organic and inorganic substances regulated by the inscrutable laws of an all-wise Providence; to the philosopher, it is simply "harmonious matter;" but to the student of applied sciences it presents an inexhaustible array of forces and elements, which lend themselves to analytic and synthetic observation. Thus, in the view of the scientist, the spectroscope and the balance may be said to prove all things, while the blowpipe and the melting pot enable him to hold fast that which is good. It is the province of science to investigate. The chemist and the physicist have to determine the nature and limits of all the material things in their ultimate relations. We may take pride, therefore, in the long and ever-increasing list of elementary substances compiled by the noble army of workers who have endeavored to unravel for us the mysteries of earth and space. The ancients supposed fire, air, earth and water to be the fundamental constituents of the universe, and these compounds are still known in literature as "the elements." Modern science, however, defines the simple or elementary bodies as "those substances which do not admit of analysis." Up to the present time over seventy such substances have been isolated. They are recognized as metallic and non-metallic bodies, but the metals are an overwhelming majority. Midway between the metals and nonmetals four elements—sulphur, phosphorus, arsenic and silicon—designated metalloids, occur. The distinction between a metal and a metalloid is a purely artificial one, based on physical rather than chemical standards. The metals are characterized by the possession, in varying degrees, of a wide range of properties, as ductility, malleability, fusibility, metallic lustre, sonorousness and thermal and electrical conductivities. The useful metals are electro-positive, and with few exceptions, they readily combine with electro-negative bodies, such as oxygen, sulphur, chlorine, etc. Consequently, the largest bulk of the metals in the earth exist in the mineral state, as ores, requiring a separation of the components before they can be put to any practical use. It is with metals as with everything else in nature—the useful members exist in greater abundance than do those of more superficial qualities.

Antiquity of the softer metals.—Copper, lead, tin, iron, gold, silver and mercury appear to have been known from a remote antiquity. They are mentioned in Holy Writ and there is every reason to believe that they were applied in many ways by the Egyptians, Persians, Hindoos and Chinese, in the earlier epochs of human history. Obviously, the crude methods employed by the ancients for the reduction of the metals greatly restricted their application. Their rude furnaces would reduce only the richest ores in small quantities and very imperfectly. The early history of metallurgy is somewhat obscure. Egypt—the birthplace of astrology, alchemy and the liberal arts, and the first of old world empires—is known historically and by exploration, as the home of many manufacturing processes, indicating a comprehensive knowledge of refractory materials, especially earths and metals. The Egyptian potters and refiners have been the models for artists, in form and color, down the generations. Prehistoric metal workers were undoubtedly engaged in fashioning such metals as are known to exist in the free or native condition. The seven elements already mentioned, with possibly a copper calamine compound, sometimes called golden-copper or native brass, comprised the stock-in-trade of the metal workers up to the beginning of the Christian era. Sacred and profane histories and the ancient mythologies contain many references to the metals and metal workers of that early period, so that Tubal Cain, Vulcan and the Cyclops, are names typical of metal workers unto this day. Exactly how much knowledge of metallurgic processes the early artificers possessed it would be difficult to surmise; but their skill in handicrafting metals for architectural and decorative purposes is beyond dispute. The Bible has made us familiar with some of the early metal refining processes, products and appliances, and it is there we trace the Genesis of metallurgy.

The fire, the pure metal, and the dross are always related as cause and effect. Gold is mentioned as being refined with silver, which sounds like the first alloy on record, and Job says: "Surely there is a place for gold where they fine it;" and again, "Iron is taken out of the earth and brass is molten out of the stone." Here let me explain that the word "refining" is applied, in technical circles, only to the later stages of the metal extraction processes, indicating the separation of impurities from metallic compounds; but it has an older and more comprehensive significance, making it embrace all the operations of reducing as well as purifying and alloying metals; and in order to avoid tedious distinctions, I take the liberty of using the term in its widest application.

Metal refining and alloying an ancient art.—Practical alloying, or the art of refining metals and alloys of metals, is an ancient pursuit which has led to many important discoveries; it has also been greatly instrumental in furthering the progress of mechanical science. It is always interesting and instructive to trace the arts and inventions to their origins. A new idea may cause a sectional uneasiness, but an old one never loses its power to guide and uplift the activities of the race. When the world was young and the children of men had leisure to dream, the interpreter of visions was a power in the land; magic became a fine art and astrology the first science—music and hieroglyphics following in natural sequence. Husbandry was the essential occupation of mankind until he learned that he could not live by bread alone. Worship made calls on his better nature, and these were answered, mistakenly, but sincerely, in the graven images of the semi-barbarous peoples. Even Israel, the chosen race, lapsed into idolatry. Thus, Aaron's golden calf became the forerunner of frequent failures as well as the first recorded work in metal founding. Such a beginning was befitting this industry, for there are many misguided workers engaged in founding metals, even now. Did not Jeremiah establish his reputation as a prophet when he said: "Every founder is confounded by the graven image."* Incidentally, the destruction of this golden calf sheds some light on the matter of reducing metals in those early days. Moses "took the calf and burnt it in the fire, and ground it to powder, and strewed it upon the water." These processes are characteristic of some ancient methods of gold refining, and the granulation of metals by strewing them upon water is still practiced in the manufacture of hard solders and shot metal, as well as in some of the modern methods of extracting metals from the earthly matter with which they are generally associated.

In all ages, it has been the aim of the metal refiner to bring out and enlarge the useful qualities of the metals, and the progress of metallurgic processes in recent times demonstrates the desirability of having the practical arts based upon scientific principles. We have learned that the chemical properties of most metals are such that only their salts are found in nature; but the ancient refiner, with his four "elements" and many empirical laws, made slow advances and few discoveries in the working of metals. Up to the time of Pliny, or the beginning of the Christian era, the metals were reduced, smelted and mixed with scarcely any definite application of chemical knowledge and with little or no effort to get rid of impurities, excepting, perhaps, in the case of the precious metals—gold and silver. Casting operations were necessarily restricted. Alloys other than the natural product of the ordinary smelting operations were practically unknown. A few mechanical processes, as the calcination and cupellation of metals, served for the separation of the noble and ignoble elements; and the proper use of fluxes had not yet been discovered. In the middle ages, the alchemists were fired with the hallucination of making gold. They formed into leagues; worked in secret upon some mystical formula; adopted signs, zodiacal and religious; and aimed, at different periods, to discover, first, an alkahest, or universal solvent; second, the philosopher's stone—a substance for transmuting base metals into gold; and third, the elixir of life—a liquor supposed to have the power of prolonging man's existence.

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*Jeremiah 10:14.

Work of the alchemists.—These dreams of the alchemists—like the dream of perpetual motion—are still unfulfilled, but Utopia is always in the future, and every new discovery seems to stir up hope in the prophetic truth of human imaginings. Scientific, like other history, repeats itself. Men pursue old fancies and discover new forces by the way. Recent researches seem to be overturning laws which scientists of former periods were at great pains to determine. Thus, with the advent of radium, Dalton's atomic theory is said to be in danger, the law of the permanence of matter is in a precarious position, and if it be true, that uranium and other metals develop radio-activity, the greatest dream of the alchemists—the transmutation of metals is likely to materialize.

The desire for gold is much older than King Midas. The mystics and magicians of the early Egyptian and Persian civilizations indulged in transmutation theories. It took centuries of alchemical research to undeceive the later schools about the gold-in-everything craze. The disappearance of the Magi and the fall of the Roman Empire opened up the way for the development of systematic chemistry and the introduction of the new industrialism. Our increased knowledge of the cosmos has been of infinitely greater value than the mere discovery of an alkahest; nevertheless, we are indebted to the alchemists, and to the minuteness of their searchings for the philosopher's stone, for the discovery of many invaluable processes and startling phenomena in the realms of chemistry and physics, and also for introducing to us that group of interesting bodies, termed the metallic alloys.

Chemistry and metallurgy are so intimately related that they require collateral study; they are allied as theory and practice in metal refining processes. Chemical science may be said to lay down the law, and be the theoretical basis of metallurgic operations, while metallurgy, viewed as a manufacturing art, and by right of its historical precedence, may be considered as the practical foundation of chemistry. Art and empiricism have always preceded science and dogma. Astrology preceded astronomy. Alchemy preceded chemistry, and the ancient metal refining processes paved the way for the more complete metallurgy of today.

Chemistry and metallurgy.—Passing from the ancient to the modern aspects of metal refining, we are confronted with the immensity of the subject. A brief summary of the processes involved in the reduction and refining of one of the metals would require a book—and a more gifted writer. Having regard, then, to the scope of this work, we must be content with a general survey of the vast field, focusing the simple principles and the more important methods of smelting and alloying metals, down to our own times.

Ores may be described as chemical compounds of metallic and non-metallic elements, from which the metals are generally obtained "by promoting a change in the chemical equilibrium." The nature of the operations by which metals are extracted from their ores depends on the chemical affinities of the metals to be extracted.

Nature works by a system of laws and affinities; and, in treating metals, the best results have been obtained by imitating the processes by which metallic compounds are built up or dissociated in nature. Of necessity, the metallurgist is forced to observe the chemical reactions following upon the elaborate processes involved in the separation of gangue or earthy matter from the purely metallic constituents of an ore. The ores from which most of the metals are obtained, occur in such great variety of combination and in such diverse conditions, that no general system of treatment could be devised for the reduction of any one class. Metallic oxides, sulphides, carbonates and silicates constitute the majority of the minerals yielding the useful metals.

The value of an ore depends upon the metals it contains and upon its susceptibility to metallurgic treatment. Very often the presence of the precious metals influences the choice of a refining process and necessitates more careful handling and more exhaustive treatment of the ores. But the metallic content is not always the most important consideration in the treatment of an ore. Some ores contain sufficient suitable fluxing material to reduce the metallic contents in the form of coarse metal; others lack this excellent property and have to be fed with artificial fluxes. In recent years, many low grade ores, which could not be economically reduced in former times, have, owing to the more exhaustive and economical reactions of modern metallurgy, and the manufacture of practical by-products from the materials of reduction, been increased in value beyond their intrinsic worth.

Metallic combinations.—Metals may exist in any of the three states of matter, solid, liquid or gaseous, the condition varying with and being nearly always determined by the temperature. The possibilities in the way of metallic combinations are infinite. Metals combine with each other and with other elements in nature, producing compounds the decomposition of which demands a close observance of chemical and physical laws, as well as an intimate acquaintance with the mechanical processes of refining. The association of different elements and the chemical conditions binding them together can only be broken up by the application of suitable chemical reagents. Heat is the principal agency by which the cohesive force of materials is diminished, and it is because the application of heat promotes the operation of the laws of chemical energy that the metallurgist is so strongly addicted to the agency of fire.

Treatment of ores.—The treatment of the ores for obtaining the metals is mechanical and chemical. The mechanical treatment is preliminary to the roasting and reduction processes and consists in crushing, washing and classifying the ores according to their richness and the nature of the gangue. The process is known as concentration and its action is based upon the different specific gravities of the substances which are associated in the ore, advantage being taken of the different speeds at which their particles will subside in a column of water. Ores which are mineralized in large masses, or crystals, are adapted for coarse concentration; on the contrary, ores which contain the valuable mineral in a finely divided state must be crushed finer in order to liberate the finer particles.

The degree of fineness to which an ore should be crushed depends on the nature of the mineralized ingredients. The solvent action of water eliminates worthless substances, diminishes the labor of dressing and leaves the metalliferous contents in a concentrated form. Many ores of lead, zinc, copper and iron are prepared for heat treatment, or chemical processes, by the coarse method of concentration, but the ores of silver, gold and tin usually require more careful dressing and fine concentration.

When the chemical nature of the ore is known, it is generally easy to arrange conditions which will assist in the reduction of the metal. It is thus the concentrates obtained from the mills are prepared for the further processes of roasting and smelting, or, if the precious metals are involved, chlorination, cyanidation and amalgamation.

The local facilities and the chemical susceptibilities of the concentrates, determine the smelting process most likely to be successful. In most smelting operations, the reduction is effected by the abstraction of oxygen from some oxidized compound of a metal, or, as it is technically termed, deoxidation. On the other hand, oxidation is frequently important in metallurgical processes, as it is a means by which substances that are readily oxidized may be separated from others which are less readily oxidized.

Many ores contain substances which generate volatile combinations under the influence of heat and air. This process is technically known as roasting; it removes volatile impurities and is generally preliminary to the fusion or smelting operations by which the reduction of the metals contained in the ores is accomplished.

Some ores and alloys are separated by the process of liquation, *i. e.*, by taking advantage of the difference in fusibility of the components. For example, when an ore is exposed to a gentle heat sufficient only to melt the most fusible constituent of the mass, it is separated from the unmelted residue, or in the case of alloys, if the elements do not enter into chemical union, there is always a tendency for them to separate out according to their densities and in relation to their fusible properties.

The solvent action of certain liquids frequently affords a convenient means of separating metals from the earthy matter enveloping them, consequently many of the ores are treated with acid or other liquids previous to the precipitation and reduction of the metals contained therein.

It would be difficult to go into the details of metal manufacture since the operations vary with the nature of the ores and the value of the metals which they contain. Prof. Roberts-Austen, in his "Introduction to Metallurgy," has given a general summary of the methods of extracting and reducing metals from the ores, under the following heads:

1.—Liquation.

2.—Distillation and sublimation.

3.—By the reduction of metallic oxides at high temperatures as ($2\ PbO + C = 2\ Pb + CO^2$).

4.—By the decomposition of metallic sulphides by means of iron at a high temperature, as seen in the equation, ($PbS + Fe = Pb + FeS$).

5.—By cupellation, which is probably the oldest method of extracting metals from their ores. When lead is molten it oxidizes rapidly, forming litharge, which has the property of dissolving other metallic oxides and combining with them into a slag.

6.—By amalgamation, *i. e.,* by taking advantage of the powerful solvent properties of mercury.

7.—By electrolysis.

8.—By crystallization, as in Pattison's method of extracting silver.

9.—By the wet process—dissolving in acids and precipitating; or forming compounds which can be acted upon by suitable reagents.

This by no means exhausts the list of methods by which metals may be extracted; there are many auxiliary processes and combination methods which could only be dealt with by describing the complete metallurgy of the metals.

This is especially true as regards the recovery of the "noble" metals. Metal refiners have such a wide range of methods to select from that it is sometimes a hard matter to decide which is the best treatment for a particular ore. The fact is, many good mines have failed to pay dividends because the economies of the extraction processes did not receive proper attention.

Whatever method of decomposing the mineral may be adopted, wet or dry, all the labors of metallurgical processes are directed to the same end, to reduce the substance to the metallic condition and to separate impurities from the metals recovered.

Every new reaction or change of the chemical relations of the material, contributing to its decomposition, may be turned to account for the recovery of the metal, or for the manufacture of some commercial product. Hence the increase in the number of metallurgic processes, and the adoption of combination methods giving better control of the commercial values.

Treatment of complex ores.—Perhaps the most prominent feature of modern metallurgy is the thoroughness with which the various elements contained in the ores, or in the resulting metals, are marshalled and utilized. In these days, the methods of isolating and purifying the metals are better understood, the complex ores can be more fully treated, and the results regulated with more precision than ever before. There are few negligible quantities contained in the ores nowadays. The metallurgic methods are so comprehensive, and the chemical reactions so well controlled, that the real value of the various ores is not to be gaged by the proportions of the metals they contain. There is no doubt that the metal refining industry, or, to be precise, applied metallurgy, is undergoing a revolution. More is being taken out of the ores now than was possible a few years back; the quality of the metals produced is superior, the grades are more uniform, and the cost of production is being steadily reduced.

To illustrate this point I quote this paragraph from a current newspaper: "Broken Hill ores, which hitherto have only been treated for the silver and lead content, are now to be worked for zinc and sulphur also." Thus, from the residue of an older metallurgical process, a new industry is to be created; and by the additional profit from zinc (16 per cent), which was formerly ignored, and the manufacture of sulphuric acid, increased prosperity, in this instance, is assured.

Yet another example of remarkable development made in recent years is the smelting of concentrator slimes, which were practically refuse. By a simple process of sintering, or kiln roasting, and then smelting, thousands of tons are being converted into marketable metals—and profit!

As illustrating a modern process designed to economize the products of ores containing precious metals combined with volatile metals and elements, take Dr. Hoepfuerer's method of recovering zinc from argentiferous blends in which the percentage of iron is too large to permit the ordinary distillation method being used. "The ores are at first roasted with common salt, resulting in the production of zinc chloride and sodium sulphate. These two soluble salts are then leached out, and the latter separated from the former by crystallization in the cold. The zinc chloride is then treated electrolytically, using carbon anodes, and for cathodes, a revolving plate of zinc. The chlorine as it escapes is absorbed by lime, making it a marketable product. The precious metals remain in the leached residues in the tanks." If rich enough, these may be sent direct to the smelter; if not, they would require concentration.

This example is typical of the modern improvements and economies effected by studying the properties and capabilities of the associated minerals, ores, fluxes and fuels, and the obvious advantage of employing electricity for the reduction and separation of the metals.

Electrical reduction of ores.—The selling price of a metal depends largely upon the readiness with which it is reduced from its ores. Only a few metals are reduced to the metallic state from their compounds by heat alone. Assistance has to be rendered by reducing agents. In modern metallurgy, the electric current promises to become one of the most important of such agents, as its action is direct and readily applied. The problem is to separate the metal from the non-metal with which it is in combination. The current does this with no intermediate steps. Thus, common salt fuses at a red heat, and if a current is passed through the molten mass between carbon electrodes, the metal sodium is liberated at one end and the gas chlorine at the other. Great technical difficulties have been met in the application of this simple method, but they have now, to a large extent, been overcome. An older plan is to heat the ore with carbon, which, for example, takes away the oxygen of a metallic oxide to form the gaseous carbon dioxide, which escapes. Hydrogen reduces oxides in a similar way, water being formed. Another plan of reduction is to use another metal, particularly aluminum, which is able to replace it in the compound, and so set it free. With aluminum, great evolution of heat takes place, sufficient to melt the reduced metal. This is the basis of a well-known process for hard soldering steel rails, and so forth. In a like way, sodium was formerly largely used in the reduction of the rarer metals, which greatly increased their cost; but now electric practice is replacing it. A very important case of reduction is that by potassium cyanide, which takes the oxygen of an oxide to form a cyanate. More and more, however, the current is coming into play. Thus, formerly, the production of phosphorus implied the treatment of bone-ash, or natural phosphates, with sulphuric acid, but recent improvements in the electric furnace have made it possible to smelt either, mixed with charcoal, for the direct production of the element. The advantage here lies in the enormously high temperature of the electric furnace. To sum up, the modern methods of producing metals for the market are characterized by:

First, the systematic observance of chemical principles.

Second, the adoption on a large scale of laboratory methods.

Third, economy of power and material.

Fourth, the introduction of electricity as a means of decomposing metallic compounds.

Electro-technology has made enormous strides in the last decade. Electrolysis and the electric furnace have added many interesting products to the metal worker's storehouse. The former has solved the problem of producing pure metals on a commercial basis, while the latter has rendered possible the reduction and union of many refractory metals which formerly were not feasible. The progress made in the manufacture of self-hardening steels since the adoption of the electric furnace for the commercial reduction of chromium, tungsten and other hardly fusible metals, affords a striking proof of the improvements effected.

But besides furnishing power for the engineer, heat for the metallurgist, attraction for the chemist, light for the world and "vitality for weak men" as the electropathist puts it—electricity has many other uses awaiting development. Dr. Borchers says "there is no metal incapable of being reduced by electrically heated carbon," *i. e.,* the electric arc. Electricity has long been known to be a potent factor in the decomposition of metallic substances, but metallurgists are only beginning to take advantage of the fact. Electro-conductivity has been proposed as a means of testing the purity of the metals; indeed, this has already been accomplished with copper and aluminum. So it is only a matter of time till a standard of conductivity is tabulated for all the metals in a state of purity. We shall then have established a cheap test of the purity of metals.

Other proposals connected with the electrolysis of dissolved or fused metals, or metallic compounds, are also meeting with practical application, but this is hardly the place for a statement of electro-chemical theories. Certain it is that electricity has proved an economical power in metallurgy. It can be made to subdue the elements to the last atom. It may be said to fulfill the functions of the elixir of life and the philosopher's stone in one act, and now that modern scientists have wedded this sparking Vesta to the strenuous Vulcan, we may expect a numerous and gifted offspring. A well-known London humorist deplores the abolition of London fog by means of electricity! He says: "Electricians must learn sooner or later that not everything which can be done by electricity ought to be done." Metallurgists must learn this, too, and no doubt many of the old-fashioned metal refiners, who have not yet acquired the electric habit, will agree with the sentiment even if they fail to recognize the humor. The changes which have taken place in the general treatment of ores, even in the preliminary dressing and mechanical processes, would astonish the most informed refiner of a previous generation, for just as the introduction of the hot blast in the early days of iron and steel development created new conditions of working iron ores, so the later improvements in mechanical appliances and the newer applications of chemical and electrical principles have advanced and extended the operations and productions along the whole range of the metals.

II

HISTORY AND PECULIARITIES OF ALLOYS

THE story of the alloys forms an important chapter in the history of our planet. They are closely identified with the struggles of mankind to gain the mastery in empire, and in the arts and industries. It is worthy of note, that the supremacy of the nations, in successive epochs, has depended as much upon engineering, or the skill of the metal workers, as upon what is called the "force of arms." Even in our own times, the superior mechanism of a modern rifle has altered the political arrangement of the map; and in times of peace the most favored nation has generally been the most up-to-date, industrially. The ascendant nations have ever been in the van of scientific enlightenment and achievement. Warfare, which was once a matter of big battalions, is now a question of mobility and big batteries. Engines of war have always had some influence in adjusting the positions of the powers, and in many of the revolutionary periods armaments have been accounted more than troops. All of which shows that a knowledge of mechanics and the control of metals are of some importance in deciding the destinies of the nations. Alloys have undoubtedly played a prominent part in the advancement of civilization. Historically, they are co-eval with the creation—the mention of brass in Genesis leads to this inference. If we are to credit the early records, brass was first made in the bowels of the earth. It was a prehistoric discovery of nature. That brass was known to the ancients is beyond dispute. Mines containing ores from which this yelllow metal was produced, were held in high esteem, but it is doubtful if the early metal workers had any definite knowledge enabling them to control the product.

It is no uncommon thing for the natural excellencies of a mine, or its ores, to create a world-wide reputation for the metals they yield. "Veille Montagne" zinc, "Lowmoor" iron, "Banca" tin and "Lake" copper are modern examples of such fame. But not to lose sight of the historical view of our alloys, we must stretch back to mark the transition from the neolithic or new Stone Age, to the Bronze Age. What we term the Bronze Age, started early and continued late in the world's history, and even unto this day bronze shares the honors with steel and iron in constructive and ornamental metal work. Brass and bronze are often confounded by people who ought to know better. They are two distinct alloys —the former being composed of copper and zinc, and the latter being a mixture of copper and tin—and there are decided contrasts in their characteristic properties.

Bronze in the world's history.—The world's history might easily be written in chapters on bronze, the opening numbers of which may be roughly summarized thus:

Chapter I.—Palæolithic man, worn with the worries of the Stone Age and grumbling at the necessity for renewing the cutting edge of his uncouth implements, expressed in the hearing of his grandson a longing for more enduring tools. The boy, eager to acquit himself, after long and adventurous search, brought forth, triumphant, from a fissure in the Great Rock, a nugget, which, for want of a better name, was afterwards called *Aurichalcum, i. e.*, golden copper. And thus originated the first artificer in metals!

Chapter II.—The artificers grew and multiplied, and the harvests being sooner garnered with the improved appliances, they waxed thoughtful, but no less industrious. Bending their minds to those things most worthy of worship, they adorned the temples, made god-like images and warlike weapons, raised monuments to their heroes and generally behaved themselves in a manner becoming the fortunate scions of the ever memorable and almost everlasting Bronze Age.

Chapter III.—In the Middle Ages, the church being all-powerful and desiring to proclaim the fact for all time, inspired the now skillful bronze founders to invent some *striking* vessel which would yet speak when her ministers were dead. The bell-founding feats of these patriarchs are beyond us today, and we have evidences in many parts of the world that they were no fool molders anyhow!

Chapter IV.—When the so-called civilization of the Western nations created that lust for empire, which still threatens to engulf us, those docile workers, now called brass founders, were requisitioned to produce an engine which would send the superfluous savages occupying the desirable places of the earth, into "Kingdom Come." With characteristic ingenuity, befitting such highly developed craftsmen, they compounded a metal *able to withstand the shock!* Gun-metal, as you are aware, is used to this day—sometimes successfully. It has a name which is universally admired and for *that* the public pay ungrudgingly the highest price. Some day an enthusiast from the ranks of the "Brassies," with a quicker imagination than I, may be inspired to write up more fully the historical side of brass founding. Meanwhile, we must get back to the more practical aspects of the subject.

Definition of bronze.—The word bronze is of comparatively modern origin, being similar to the Italian *bronzo,* which is in all probability derived from *bruno,* signifying the brown color of the metal. While some of the ancient bronzes compare favorably with the later products of the metal industry, they invariably contain traces (sometimes even considerable percentages) of lead, nickel, silver, iron, and gold. It is inferred from many examples of these early bronzes, that the ancients had not acquired the modern art of separating the individual metals—copper and tin—from the ores. The early smelters produced the bronzes by a judicious mixture of the ores, and were probably unaware of the impurities locked up in them. Ores are occasionally alloys, or combinations of the metals, and doubtless the earliest alloys used were reduced direct from the ores by the simple application of heat. The systematic study of the alloys was not begun until the latter half of the eighteenth century, but methods of tinning and gilding metals and the use of amalgams were known to the Romans. Bronze casting was also an important industry with them. Statues were erected in such numbers that they finally became a by-word.

According to Pliny, four varieties of Corinthian copper were made, all four being alloys of gold, silver and copper. The white variety contained an excess of silver, the red had an excess of gold. The third was a mixture of the three metals in equal proportions, and the fourth variety, hepatizon, derived its name from its having a liver color. It is a remarkable fact that metals seldom attain to their fullest usefulness in a state of purity. However desirable pure metals may be for some manufacturers, as dyes, drugs, or alloys of the precious metals, it is generally recognized that but little can be done with a metal until it has been combined with some other element.

It would seem to be a law in nature that none of the elements reach their greatest usefulness until they have been united with some other substance by mutual affinity. Water (H_2O), air ($O\ \frac{1}{5} + N\ \frac{4}{5}$), salt ($NaCl$), and many other substances which minister to the support of life may be cited as compounds typical of the chemical energy which permeates the natural world. Nowhere is this power of attraction and chemical union more evident than in the mineral kingdom. The earth is full of compound substances; and with all the accumulated science and technical insight of modern philosophy, the last word has not been said on the condition and constitution of matter. And there are marvels in metals, just as truly as there are wonders in chemistry. In the sixteenth century, the "Gnomes" of Paracelsus,—sprites said to preside over the inner parts of the earth and to reveal its treasures—were invented as a foil to the inquisitive. Later, the "phlogiston" of the Alchemists furnished a convenient reason for chemical changes in the metals.

Unexplained problems.—In the whirligig of time many such visionary, extravagant theories have been dissolved, but so far as alloys are concerned, there still remains a bewildering host of problems which cannot be explained by any available scientific rules. We have to acknowledge the existence of several allotropic conditions of metals and alloys which defy explanation. An alloy of platinum and iridium shows the remarkable property of being attacked by acids to which the pure metals are entirely indifferent.

It has not yet been demonstrated how the famous Mitis castings made from a mixture of wrought iron, cast iron and aluminum bronze, revert from the fibrous condition, back to their original strength and structure; or how two soft metals like tin and copper unite to form a flinty compound like bell metal or speculum; or how two malleable metals like gold and lead lose that property, immediately a trace of the alloy is introduced; or how two stable metals like nickel and aluminum, in certain admixtures, crumble into powder a few hours after they have been combined; or how aluminum should exert such a powerful influence on the color of gold as to produce the remarkable white colored alloy (gold 90, aluminum 10) discovered by the late Prof. Roberts-Austen. Many other phenomena bearing on the relations of the metals entering into combination as alloys, could be instanced. From recent experiments, M. Guillimane has shown that a ferro-nickel alloy, containing 25 per cent nickel, is almost as insensible to the action of a magnet as copper, notwithstanding the fact that iron and nickel are two of the substances most readily attracted by a magnet.

A still more singular property appears in the discovery that the magnetic properties of the constituents may be conferred on the alloy by subjecting it to great and rapid cooling. Thus, we have an alloy, which, at ordinary temperatures is non-magnetic, but which becomes magnetic when cooled further. Advantage has been taken of this unique property of ferro-nickel alloys in the construction of some new scientific instruments and electrical appliances. But we must not make too much of the novelties presented by some alloys; the practical points of alloying are of more importance than the enumeration of metallic curiosities. The ordinary definition of an alloy teaches that it is a compound of metals obtained by fusion.

Definition of alloy.—The alchemical usage of the verb *alloy*, meant, to temper one metal with another, the alloy always being the inferior metal, as copper in gold, or silver. This rendering still clings to us. Sterling silver is an alloy of 925 parts, by weight, of silver, combined with 75 parts of copper. In the language of the assaying office, the copper in this example is termed the *alloy;* but in a technical sense the metal resulting from the combination of these proportions of silver and copper, in a liquid condition, is the alloy proper. Again, in brass foundry practice, the metals which are added to the molten copper to make an alloy—as lead and zinc in cock metal, or tin and zinc in gun metal mixtures, are termed the *composition;* but an analyst would state the composition by the percentage of *all* the constituents contained in the alloy. Jewelers sometimes employ zinc in gold alloys; it is generally used in the form of brass and is known by them as *composition.* Other examples of the misuse of the word alloy, are the well known trade terms, *hardening, temper,* etc. It is evident we begin to need a new definition of an alloy. The final product derived from the mutual solubility, or the fusion of two or more metals, is generally regarded as a perfect alloy. But some years ago the union of a metal with a non-metal was not recognized in that way. Cast iron has only recently been brought under this category, and many of the modern alloys now manufactured as commercial specialties, do not come under the old description of perfect alloys. It has also been customary to regard all mixtures containing mercury as amalgams; but there are at least two alloys with a fair content of mercury, which cannot be so classed, namely, Dronier's malleable bronze, and Kingston's anti-friction metal. So that it would seem wiser to allow that the union of a metal with any other elements should be treated as an alloy, *so long as the solidified mixture retains the essential characteristics of a metal.* From a technical standpoint, the commercial value of the metals entering into an alloy should not be taken into account at all. The *fineness* of gold is a relative term which might be as well expressed by *hardness,* or any other quality.

The importance of an alloy is not regulated by the price of its components as some erroneously imagine. The things that matter are its chemical and physical properties and its suitability for the duty laid upon it. The presence of metalloids has a very decided influence on the structure, strength and solidity of metals and alloys. Sometimes it is a good influence, but not infrequently it is for evil. The worker in alloys is therefore compelled to be more careful in his manipulations than the worker in metals which are not alloys. Besides being more difficult to tool and less fit for wear and tear, unalloyed metals are, as a rule, not so well adapted for castings. Copper, nickel, and aluminum are very tenacious metals in the form of rolled sheets, rods, or tubes; but if the same metals are reduced to the molten condition and poured into molds, the castings are generally disappointing, both in respect of solidity and tenacity. Heated to fusion, these metals absorb oxygen, and in cooling down to the solid condition they retain more or less of the dissolved gas, which produces a honeycombed structure.

To overcome this defect, and to enable the founder to procure homogeneous castings with these metals, Messrs. Cowles have advocated the addition of a small percentage of silicon in the case of copper; Dr. Flietman advised the use of magnesium with nickel; and in the case of aluminum, Dr. Richards has recommended an addition of zinc or copper. Comparatively few castings are made from unmixed metals nowadays. The principles of alloying are found to be so convenient and so advantageous, that with the exception of electrical appliances, better results may be achieved, and better mechanical properties may be imparted to the castings, if the mutual solubility of metals is regarded in the preparation of the metal to be cast.

The art of alloying metals involves many principles, requiring much care and intelligence to attain the qualities desired in the finished product. Alloying has reference to the chemical relations of the metals and the methods of preparing and combining them; but, with the exception of some few dual alloys, as alloys of copper-tin, copper-zinc, lead-tin, silver-copper, aluminum-copper, etc., our knowledge of the effects of combining metals is far from being complete. Systematic researches have been confined chiefly to the copper alloys. Indeed, copper occupies much the same position in the industrial arena that gold has in the commercial world. It can be manipulated in more ways and with less uncertainty than any of the other metals. This is due to the wide range of properties copper is able to impart to, or receive from other metals. The changes effected by alloying metals are generally more marked if there is considerable difference in the characteristics of the metals used. The alloying of metals has generally a tendency to promote fusibility, fluidity and hardness; and for the purposes of castings, the homogeneity of a metal is nearly always improved by the addition of some other element. Color is also an important feature in alloys, but the coloring power of metals is more variable in alloys than in some other compounds employed for dyes and pigments. Ledebur arranges the useful metals in the following order: Tin, nickel, aluminum, manganese, iron, copper, zinc, lead, platinum, silver, gold. He says: "Each metal in this series has a greater decolorizing action than the metal following it. Thus the colors of the last members are concealed by comparatively small amounts of the first members." The alloy used for nickel coinage affords a good example. This alloy is composed of copper 75 parts, and nickel, 25 parts; the comparatively small quantity of nickel is, however, sufficient to completely hide the red color of the copper. But the color study of alloys has been pushed into the background by the more pressing need for purely mechanical effects, and variations in the physical properties of the metals are of first importance to engineers.

Combinations of metals.—The nature of alloys has always been a matter of considerable controversy. Some of the metals combine in certain definite equivalents, terms atomic proportions, to form chemical compounds. Alloys of this description seem to possess superior qualities, and to be more stable than those produced by the haphazard admixture of metals in a liquid condition. Several metals may be dissolved in one another in all proportions, to form homogeneous alloys, while others refuse to be combined in any proportions which would qualify them to be classed amongst the useful alloys. When a mere mechanical mixture of metals is formed in an alloy, distinct crystals occur with one metal, between which the other is visible. Whereas, when an alloy is formed by the chemical combination of the metals, no such irregularities appear, and in some cases, the original equivalents cannot be destroyed by remelting. So that when two metals unite to form a chemical compound, we have a new substance with properties entirely different from the properties of either of the elements which formed it, and because of the affinity or chemical attraction of the elements, it requires some superior power to separate the particles of this new combination.

It would be interesting to know if those metals which adhere well in electro-plating processes are, in any special sense, fitted to form true alloys. Electroplaters are aware that nickel adheres well to platinum, tin adheres well to copper, zinc adheres well to iron, gold adheres well to silver, mercury adheres well to tin. Is this due to chemical affinity, or does electricity contribute to the reciprocity?

Again, some metals combine very readily with certain metalloids, as iron with carbon; copper with silicon; nickel with arsenic; aluminum with phosphorus; lead with oxygen, etc.; but by the introduction of a third element the chemical relationship of these combinations is disturbed. The inference to be drawn is that the union of a metal with a metalloid, even when they form a chemical compound, is more sensitive than a chemical compound of two metals. As a rule, a small addition of a third element in a simple alloy of two metals, helps to form a bond of union between them. For example, copper and iron combine with difficulty, but copper, zinc and iron produce many homogeneous alloys of great tenacity. Again, nickel and aluminum make an unstable combination, but nickel, copper and aluminum give a series of remarkably tough and permanent alloys. Mercury and iron have no affinity for each other, but if tin is intermixed with these metals, an amalgam may readily be formed.

The behavior of an alloy cannot be deduced from the behavior of the components, neither does the apparent solution of one metal in another give any guarantee of homogeneous metal. It sometimes happens that certain proportions of the constituents in an alloy combine chemically, while others exist in a state of mixture or solution. The solidified mixture in such examples presents a mixed appearance in the fracture; this is due to the different densities, fusibilities or chemical properties of the alloying metals. Wherever there is a tendency to this condition, it may generally be aggravated by the slow cooling of the metal, or by raising the temperature of the molten alloy in excess of the heat required to render it fluid enough for castings.

The character of many alloys is greatly modified by remelting. Alloys containing tin or aluminum generally show an increase of these metals after frequent fusions; bells cast from metal which has been repeatedly remelted, acquire a disagreeable tone because of the formation and solution of oxides in the molten alloy; and alloys containing volatile metals, as zinc, arsenic, antimony, etc., may be rendered practically worthless by prolonged melting. The presence of impurities in the metals used for making alloys is also a source of trouble; very small quantities of some elements seem to have far reaching effects on the properties of alloys.

Dual alloys.—Naturally, the characteristics of dual alloys are easier maintained than combinations of three or more metals. Some of the most important alloys in the industrial arts, are unsophisticated combinations of two metals: Brass ($Cu + Zn$), bronze ($Cu + Sn$), nickel-silver ($Cu + Ni$), aluminum-bronze ($Cu + Al$), plumbers' solder ($Pb + Sn$), and standard gold ($Au + Cu$), and silver ($Ag + Cu$), are all dual alloys. Various additions have been made to these alloys with a view to improving their mechanical properties, modifying their appearance, or reducing their cost, but the essential qualities of the alloy, in each case, can only be brought out by suitable proportions of the two metals indicated, being incorporated in the manufacture. Complex alloys are on the increase; and subtle combinations are being devised to meet the wants of engineering and architecture. The alloys of the future will therefore require closer adherence to chemical principles, a better knowledge of the behavior of *liquid* metals, and some more scientific method of reduction than the open or reverberatory furnace. Delicate combinations demand delicate handling. This applies to alloys in particular, as they nearly always contain elements with weak affinities and are prone to oxidize, volatilize and deteriorate in the heat.

This work, as I said at the beginning, was started with the object of throwing a few side-lights on the practical alloys and processes of brass founding. They may have been only dim, uncertain glimmerings, but brass founding being a dark subject, the smallest ray may be an illumination in itself. It has been my aim to show:

First, that the discovery of bronze opened up the field for metal castings.

Second, that no castings have attained to the eminence of the bronze castings.

Third, in order to become successful brass founders you should honor the traditions of the trade, the chief one being "Take care of the metals, the molds will take care of themselves," and be imbued with the belief that radium may come and steel may go, but bronze will continue forever.

III

THE PROPERTIES OF ALLOYS

THE properties which contribute to the general usefulness of metals are hardness, tenacity, elasticity, malleability, ductility, density, fusibility, expansion by heat, resistance to corrosion and conductivity for heat and electricity. These properties always show some variation from the mean when two or more of the metals are combined to make an alloy. In view of the great uncertainty as to the chemical condition and behavior of fused metals with one another, it would be impossible to lay down propositions covering the general results of alloying. Every new alloy is an experiment, because the manner in which a metal affects or is affected by metals with which it may be mixed, cannot be exhibited in advance. For the most part, the chemical properties of the metals are latent and the physical properties of the alloys depend upon the chemical conditions.

Reasons for alloying metals.—Nearly all of the elements exist in a state of combination in nature, but for the uses of engineering it is necessary to separate and recombine the metals to produce alloys giving constructional advantages. The principal objects of alloying metals are:

To increase desirable qualities, as strength, hardness, toughness, or elasticity.

To lower the melting point.
To modify the color or structure.
To facilitate the production of sound castings.
To resist corrosion.
To economize materials.

Hence, there is a growing tendency to group alloys by their predominant physical properties, as high-tension alloys, fusible metals, decorative alloys, deoxidized metals, non-corrosive alloys, and light alloys and anti-friction metals.

Of the seventy-odd elements which have been isolated by the chemists, only some twenty possess properties of value in the production of commercial alloys. These are: Copper, zinc, tin, lead, antimony, aluminum, nickel, bismuth, cadmium, magnesium, iron, manganese, chromium, gold, silver, platinum, arsenic, phosphorus, silicon, mercury.

Carbon is an essential element in cast iron and steel and its alloys, but the conditions and effects of carbon in these metals and the use of the rare metals molybdenum, vanadium, titanium, etc., in the manufacture of special steels, are outside the scope of this work which purports to treat of the non-ferrous alloys in general use for castings. Besides, carbon is inert at the lower temperatures required for alloys in general. The great majority of the useful alloys are combinations of two or three metals, and the order in which the metals are stated above is approximately the order of their usefulness from the viewpoint of the foundryman and the engineer.

Two classes of alloys.—The alloys of a given metal may be divided into two classes: Those in which the metal is the chief constituent, and those in which it is present as a necessary constituent. For example, *Tier's argent* is an aluminum-silver alloy which is harder and easier worked and engraved than most other silver alloys. It consists of aluminum two parts and silver one part. On the other hand, aluminum bronze is an alloy of the second class, showing copper 90 to 97 parts of aluminum 3 to 10 parts. But for the present we are more concerned with the physical properties of alloys than with their composition.

Hardness.—The property which is most generally conferred by alloying one metal with another is hardness. The hardness of an alloy is very much affected by the rate of cooling as well as by the presence of impurities in the metals, but the relative hardness of the alloying metals gives no clue to the hardness or the fracture of the alloy. The following figures give the relative degrees of hardness for some metals and their alloys: Lead 7, tin 13, zinc 70, aluminum 89, copper 106, antimony 160, antimonial lead 12, babbitt 18, brass 164, hard bronze 244, phosphor bronze 253.*

Mechanical treatment, such as rolling, hammering, etc., hardens metals by changing the molecular condition, but when such metals are remelted they assume the normal hardness and structure on solidification. Nickel and manganese are the hardest metals entering into ordinary alloys; but some comparatively soft metals have remarkable hardening powers, such as zinc in aluminum alloys, tin in copper alloys, or lead in gold alloys. The metalloids, arsenic, silicon and phosphorus, are also powerful hardeners. By combination in certain proportions with silicon, the hardness of steel is imparted to copper. With a greater or smaller quantity of silicon the properties of the alloy vary, the high silicon-copper being a capital deoxidizing agent, while the low silicon alloys possess great elasticity and power of resistance to heat, and they conduct electricity better than any other alloys.

Another splendid example of the hardening effect of one element on another is seen in the modern alloy, "Meteorite," or phosphorus-aluminum, the phosphorus content not exceeding four per cent. In this case, as in most others, the increased hardness is not the only beneficial effect procured; better casting and working qualities accrue, and, speaking generally, crystallization is modified, the tensile strength is improved, sonorousness is increased, and a closer grain in the metal gives it a finer luster.

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*These figures refer to Baur's drill test for hardness and show the revolutions required to bore one-half inch of metal, using a ⅜-inch twist drills, the pressure on the drill being 160 pounds, and running at 350 revolutions per minute.

Fusibility.—Another general result of alloying metals is to render them more fusible. With very few exceptions, the melting points of alloys are below the mean of the metals used; sometimes they are even more fusible than the most fusible component, as for example, Wood's alloy, or any of the so-called fusible alloys containing bismuth. The influence of heat on metals and alloys is a most interesting study. The extreme temperatures necessary in modern industries have developed a new field of metallurgy which promises to reveal many dark things concerning the resistance of refractories and the chemistry of high temperatures. None of the metals can resist heat or chemical action. The electric furnace is producing today many substances which offer enormous advantages over the products available at ordinary furnace temperatures. The immediate effects of heat upon metals and alloys vary considerably. Besides the difference in the degrees of heat necessary to reduce them, the metals show considerable difference in their behavior in the heat and cooling down to ordinary temperatures. Some of them soften or become pasty before actual fusion occurs, others pass directly from the solid to the fluid state and vice versa, while one, arsenic, passes when heated directly from the solid to the gaseous state without becoming liquid. It can only be liquified under pressure. All metals are volatile to a greater or less extent but the critical degree of heat at which some of them, as manganese, platinum and chromium, vaporize, is beyond the power of the ordinary furnace.

Whenever there is a chemical union of the elements in an alloy, heat is liberated. Generally there is a marked increase in the temperature and also in the fluidity of the metal. The reaction of metals which melt at very high temperatures is not so easily controlled, therefore it is customary to make alloys requiring high temperatures by some intermediate process, say by reducing the oxides in the presence of some other substance possessing affinity for oxygen. Similarly, for the union of metals which volatilize readily, as zinc or antimony, with metals requiring high temperatures for their fusion, as iron, or nickel, the direct method of mixing is always unsatisfactory. Fortunately, the chemical affinity of the metals admits of correct combinations being made at temperatures slightly higher than are necessary to melt the less refractory metals. Thus, iron may be alloyed at the temperature of molten zinc. Copper may be dissolved in molten tin. Nickel is easily reduced in a bath of copper and platinum is attacked immediately when it is heated in contact with lead, or one of the metalloids, phosphorus, silicon or arsenic. These examples prove the common rule that alloys are more fusible than the fusibilities of the several metals would lead one to expect.

To sum up, heat has a tendency to destroy cohesion; within certain limits it causes expansion proportional to the degree of heat; it lowers the tensile strength of most alloys and it affects the mechanical properties of different metals in different ways as evidenced by the various methods of working them in forging, welding, tempering, rolling, drawing, stamping, spinning, soldering and casting. Further, the action of gases on molten metals interferes with their molecular arrangement and hinders the formation of homogeneous alloys. At high temperatures the gases are more active and the metals are more easily permeated by them; it is always a wise precaution, therefore, to alloy the metals at as low heats as practicable. The alloy may afterwards be raised to the proper heat for casting, with better prospects of retaining the exact proportions and characteristics desired.

Density.—The majority of the useful metals are between seven and eight times heavier than an equal bulk of water. Density, or specific gravity, is used as a term of comparison expressing the relative weights of equal volumes of different substances, and the metals are generally compared to the space occupied by 1 c. c. of water at 0 degrees Cent. No body is perfectly dense so as to have no interstices, or be destitute of pores, but the density of metallic substances may be considerably increased by mechanical treatment. The specific gravity of an alloy is sometimes greater and sometimes less than the mean of its components. When the density is increased, contraction has occurred, and chemical combination has probably taken place; but when the density is lessened, it shows that there has been a separation of the particles in the process of alloying, conditioning the expansion of volume. With the exception of bismuth, all metals are denser in the solid than the liquid state. As a rule, alloys are heavier than their calculated specific gravity, but a curious exception is the alloy containing aluminum, 18.87 per cent and antimony, 81.13 per cent. Its theoretical specific gravity is 5.225, which is the density it would have if its components combined with no contraction or expansion of volume. Its true specific gravity is 4.218. This shows a large expansion of volume during alloying which is clearly illustrated by the following figures: 7.07 cubic centimeters of aluminum alloying with 12.07 cubic centimeters of antimony, produce 23.71 cubic centimeters of alloy. This alloy is also an exception in the matter of fusibility. Antimony and aluminum both melt in the region of 600 degrees Cent., yet the alloy does not melt below 1,080 degrees Cent.

Working properties.—At this point we notice some of the working qualities of the metals and alloys. The leading characteristics of the metals are malleability, ductility and tenacity. The usefulness of metals and alloys depends to a great extent upon their classification, high or low, under these three headings. Of course, for castings, tenacity is always the most important property; cohesion is the first desideratum in cast pieces and a high tensile strength combined with toughness and elasticity ranks the metal or alloy well up in the list of useful structural materials.

The relative strengths and the toughness of some important copper alloys are graphically depicted in Fig. 1.

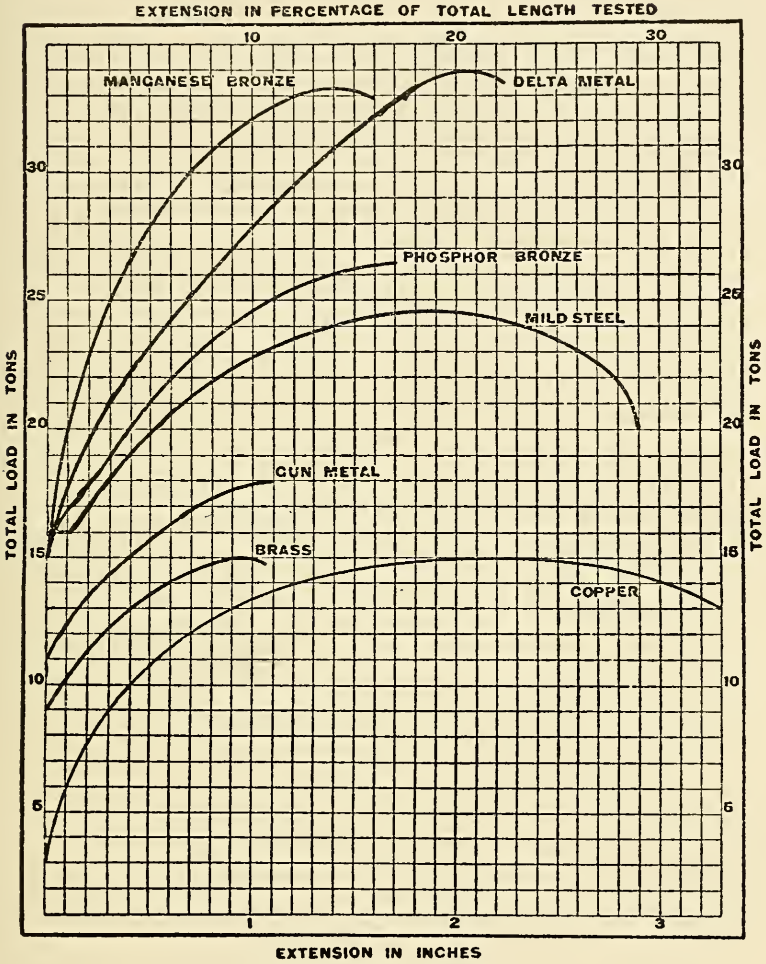

Fig. 1—Relative strengths of copper alloys

When metals are mixed together to form alloys, changes occur in the structure and physical properties of the product. Indeed, the modified properties of alloys are often of greater practical value than the independent use of the simple metals. The properties of alloys are widely different from the ratios of the combining metals. Copper and lead are both highly malleable, but the alloy known as pot metal is not; copper and tin are comparatively soft, yet the alloys, bell metal and speculum, are harder than steel. The fluidity of zinc, melted in the presence of iron, is diminished, but its malleability is increased. Alloys of copper and zinc are more ductile than copper; alloys of aluminum and tin are less ductile than aluminum. From these examples it may be judged that the relative properties of the metals do not continue in their alloys. Further, given the properties of a definite alloy, the effects of introducing even a trace of a foreign substance into it could not be foretold by any reasoning from analogy.

As a rule, metals of similar character unite to form comparatively weak alloys, and only where the constituent metals show great dissimilarity in properties do we get alloys that are united by the strong bonds of chemical affinity.

Fracture.—The workability of metals and alloys depends largely upon their structure. Brittle metals show a feeble resistance to dynamic tests and they must be sparingly used in alloys that require to have good mechanical properties. Combinations of antimony and bismuth, bismuth and zinc, or antimony and zinc, are on that account useless in the arts.

The mechanical value of structure in metals may be illustrated by the changes produced by increasing the content of a given metal in an alloy, zinc in copper for example. Beginning with pure copper we have the highly malleable and ductile qualities shown in the silky and finely fibrous fracture of the metal. By adding zinc up to 40 per cent, the metal assumes different structures at various stages. With 10 per cent zinc, the fracture is coarsely crystalline; with 20 per cent it is finely fibrous; at 30 per cent it is granular and it becomes more finely granular with additional increments up to 42 per cent. Meanwhile the tensile strength of the metal has steadily risen from 27,800 pounds to 51,000 pounds per square inch. Beyond the 40 per cent limit, ductility, extensibility and strength decrease and at zinc 60 per cent, the fracture is vitreous conchoidal, with a tensile strength of only 3,727 pounds per square inch. Metallic fractures have been classified as:

Crystalline.—Metals presenting this appearance are weak, as rupture occurs by the separation of adherent facets; examples: antimony, zinc, bismuth.

Granular.—This fracture resembles sandstone. The high tension alloys of modern times are all finely granular. The principal features of this structure are homogeneity, cohesion and *flowing* power.

Fibrous.—The strongest and most readily worked of all metallic structures. Wrought iron is a good example of this fracture

Conchoidal.—Metals possessing this fracture are hard, highly elastic and brittle, example, bell metal.

Columnar.—This appearance is presented by some metals when they are broken hot. The metal has a tendency to separate in long fingers across the thickness of the ingot; example, tin.

It is a common occurrence to find two or even three kinds of fracture in a single specimen of an alloy like yellow brass, or German silver; usually the granular and the fibrous, and the granular and finely crystalline structures are associated with each other.

Of course it is the aim of the founder to produce a metal of uniform structure, but metallography has revealed the fact that alloys, even when they are apparently homogeneous, present compound structures, and in many cases the direction in which the different forms merge and settle contributes to their efficiency. Generally, the more rapidly a metal is cooled from the molten state the more regular the fracture when it is broken cold, the reason being that there is less time for impurities and segregating elements to gravitate toward the surface or the center of the mass. We do not recommend judging the value of metals, especially alloys, by the fracture. It is well known that different treatments impart different properties to metals having the same composition. Fractures vary with the temperature and the manner in which the rupture has been produced. An ingot of yellow brass, broken between supports at 60 degrees Fahr., will present a granular appearance, while the same ingot, broken at 600 degrees Fahr., exhibits a fibrous fracture, as No. 6, Fig. 2. Another example of a hot break is No. 2, the columnar structure, procured by heating an ingot of plumbers' soft solder and striking it sharply with a mallet. No. 3 is an aluminum-zinc alloy and the fracture is somewhat crystalline. The bronzes afford the best examples of granular fracture, No. 5, Fig. 2, and No. 7, Fig. 3, are manganese bronze and phosphor bronze, respectively. As showing the typical fractures of copper-tin alloys with increasing proportions of tin, No. 8, Fig. 3, coarsely granular, is a sample of the standard gun metal (9 and 1 alloy) ; No. 4, Fig. 2, is a hard railway gun metal (7 and 1 alloy), and No. 1, Fig. 2, is a speculum alloy (2 and 1) used as a *hardening* for babbitt metals. This fracture is highly conchoidal and the metal is brittle as glass and harder than steel. The tests which are sometimes made by gripping the metal on trial in a vise, and observing the angle through which it bends, or the number of blows required to break it, can only give the roughest idea of its capabilities. To get the true history and constitution of the metal, a closer examination and more accurate measurements are necessary.

The two factors which determine the condition of alloys are their chemical composition and their physical structure. Chemistry reveals the former and metallography, the science which has lately shed so much light on the microstructure of metals, interprets the condition and the limitations of the latter.

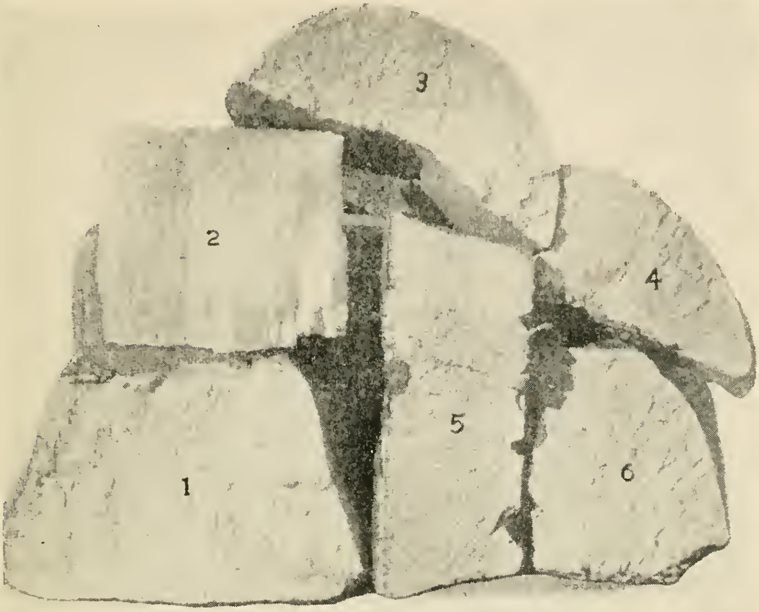

Fig. 2—Fractures of alloys

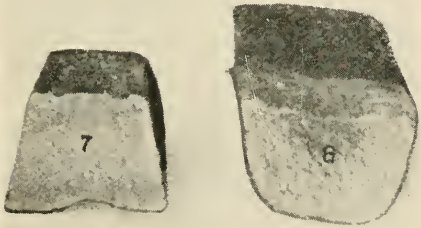

Fig. 3—Fractures of alloys

Conductivity.—All metals are good conductors of heat and electricity. Their relative conducting powers according to Matthieson, Franz and Weidemann, are given in Table I.

Electrical conductivity is greatly diminished by a rise in temperature as well as by impurities in the metal. Alloys, as a rule, are very poor conductors and on this account the metals which occupy the lower positions in the following table are best suited for resistance coils, etc. The Cowles company prepares a white alloy containing copper 67.5, zinc 13, manganese 18, aluminum 1.20 and silicon 0.5, the electrical resistance of which is about 48 times that of copper and 37 times that of the standard German silver, considerably greater than that of any other material known which is capable of being drawn into strong, tough wire.

TABLE I

Relative Conductivity of Metals

	For Heat	For Electricity
Silver	1,000	1,000
Copper	748	941
Gold	548	730
Aluminum	....	511
Zinc	....	266
Platinum	94	166
Iron	101	155
Nickel	....	120
Tin	154	114
Lead	79	76
Bismuth	18	11

The resistance of alloys is not affected by changes in the temperature to the same extent as the pure metals; on the other hand, the purity of the metals, silver, copper, aluminum, etc., may be tested, and impurities detected by the diminished transmission of electric force. This is the latest tell-tale for adulterations or impurities in new metals. Owing to the presence of oxides, or to the fact that of their being melted in contact with the fuel cast metals, copper or aluminum, have not the high conductivity of electrolytically or chemically prepared metals.

Peculiar properties of alloys.—Alloys generally have properties differing in kind and degree from their constituents. Some metals alloy freely in all proportions and present few difficulties in working, such as, silver and copper, copper and zinc, tin and lead. Others like lead and aluminum, or zinc and lead, cool out in layers. One cannot calculate the physical properties of an alloy from the physical qualities of the respective metals; small additions sometimes effect enormous changes. Alloys of brittle metals are always brittle, but the other qualities of metals do not continue in the same manner. The fracture is an index of the conditions of an alloy at the time of rupture, but the same alloy when remelted, may be unworkable, and when it is again ruptured the structure may be totally different owing to heat treatment.

Alloys at critical temperatures.—A series of experiments conducted by Percy Longmuir, and embodied in a paper presented at the American Foundrymen's Association convention, in 1905, showed the remarkable variations in the properties of alloys, due to casting temperature. The behavior of the alloys was observed at certain critical temperatures and the results were summarized as follows:

**High* casting temperatures, Fig. 4, favor a large, ill-developed type of crystallization, giving a characteristically *loose* type of structure. Fair casting heats, Fig. 5, favor a distinct but yet interlocked structure, and the crystal junctions are not so marked as is the case with the lower temperatures. Low casting temperatures, Fig. 6, give a most pronounced type of crystallization and the crystal junctions are very sharply defined, apparently forming routes along which fracture readily travels.

High casting temperatures give a loose structure.
Fair casting temperatures give an interlocked structure.
Low casting temperatures give a sharp structure.

The behavior of castings possessing these types of structure under steam or water test is as follows: Loose structures allow steam or water under pressure to ooze through the minute interstices of adjacent crystals. Interlocked structure effectually prevents any percolation of this kind, and the castings are therefore tight within all pressures up to their limit of deformation. Sharp structures familiar to castings poured at a low heat will, if the crystal junctions favor, and they generally do, offer microscopical routes of penetration similar to those of high temperature castings.

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*From the *Proceedings* of American Foundrymen's Association, 1905.

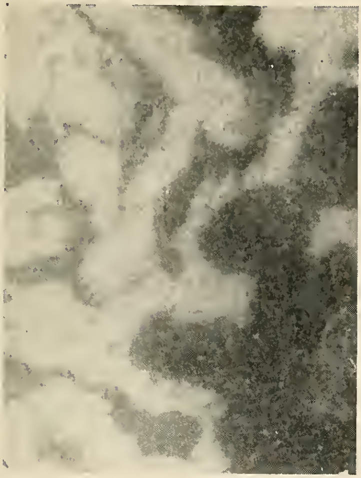


Fig. 4—Muntz metal poured at the "high" temperature

(Magnified 260 diams.)

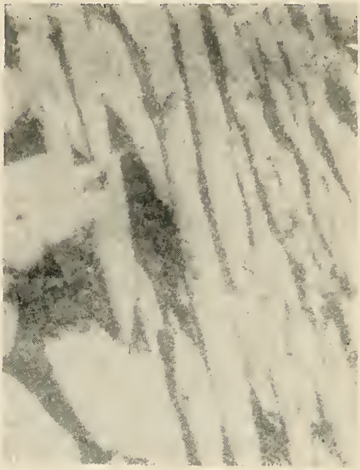


Fig. 5—Muntz metal poured at the "fair" temperature

(Magnified 260 diams.)

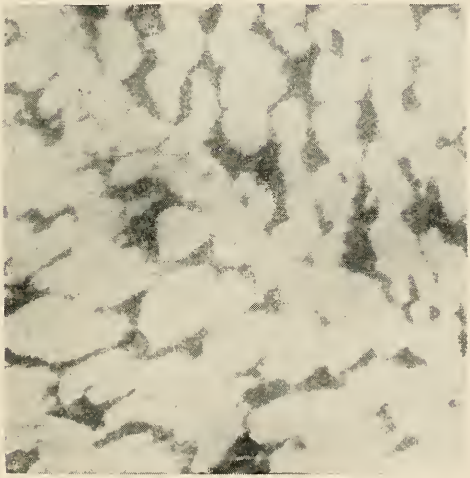


Fig. 6—Muntz metal poured at the "low" temperature

(Magnified 260 diams.)

The accompanying tables reveal some of the remarkable effects produced by slight variations in the casting temperature of typical alloys.

A type of high quality steam metal in British practice is formed of copper 88 per cent, tin 10 per cent and zinc 2 per cent, and the results shown in Table II are characteristic of many experiments on this type of alloy.

TABLE II

Analysis			Casting temperature, degrees Cent.	Maximum stress, tons per square inch	Elongation, per cent in 2 inches	Reduction of area, per cent
Copper per cent	Tin per cent	Zinc per cent				
87.5	10.2	1.8	1173°	8.37	5.5	4.23
			1069°	14.83	14.5	16.71
			965°	11.01	5.0	6.36

A usual specification for castings of the foregoing alloy is a tensile strength of 14 tons per square inch, an elongation of not less than 7½ per cent on 2 inches, whilst steam fittings must pass a water test of 1,700 pounds. Evidently the first and third castings would hopelessly fail to meet such a specification; yet the three were poured from one 60-pound crucible, and the second one is separated from the first and third by the narrow time margin of only two minutes on either side.

Table III embodies results obtained from copper-zinc alloys.

TABLE III

loy	Analysis		Casting temperature, degrees Cent.	Maximum stress, tons per square inch	Elongation, per cent in 2 inches	Reduction of area, per cent
	Copper	Zinc				
Red Brass	89.6	10.2	1308	6.85	13.2	12.65
			1073	12.64	26.0	30.28
			1058	5.67	5.5	6.64
Yellow Brass	73.0	26.0	1182	11.48	37.7	31.40
			1020	12.71	43.0	35.66
			850	7.44	15.0	15.25
Muntz Metal	58.6	40.5	1038	12.45	6.0	10.60
			973	18.88	15.0	16.10
			943	16.28	9.5	14.81

The results obtained from the red brass alloy which is largely used as a brazing metal are of special moment, and it will be noted that a fall of 235 per cent in casting temperature doubles the mechanical properties, while a comparatively slight further fall results in a very considerable lowering of these properties. The yellow brass results follow the same order, but here the fair casting heat appears to extend over a wider range, for the two first results are not greatly different. The third one, however, speaks very powerfully as to the influence of a low casting temperature. The susceptibility of a high zinc alloy to variations in casting temperature is well shown in the Muntz metal results. Each of the foregoing alloys being constant in composition and every condition save that of casting temperature being identical, it necessarily follows that variations in mechanical properties are determined solely by variations of initial temperature.

The crystalline structure of metals was discussed by Mr. Longmuir as follows:

Crystallization begins in a number of centers and proceeds until the areas meet. This granular structure of pure metals seems to be quite universal. The crystalline elements in a grain are all ranged in the same direction or have the same orientation but the elements of two adjacent grains have different orientation. The result of this is that when light is thrown obliquely on the surface of a pure metal, it appears to consist of light and dark grains, but these are all of the same kind, as may be proved by rotating a specimen, when the dark grains become light and the light ones become dark.

Some metals, as soon as cast, are fibrous and uncrystalline, but become brittle and crystalline when heated and cooled, or hammered, or worked in any way. A *high* casting temperature conduces to the formation of large crystals with most alloys, hence it is desirable to pour the molten metal at a moderate or *fair* temperature, and make provision for cooling the castings as quickly as possible. This applies very particularly to anti-friction metals.

From the Cantor lectures by D. T. Kirke Rose, published in the Journal of Society of Arts, Nov. 15, 1901, we take the following:

Eutectic alloys.—Eutectic alloys have a number of characteristics in common. They have a lower melting point than that of any mixture containing their constituents in different proportions, and these constituents may be either elements or chemical compounds; and they consist, not of a single solid solution, but of a mixture of two solid solutions. These two solutions separate from each other only at the very moment of solidification of a single solution, and consequently the crystalline particles are very small, and the structure minute. The separation of the eutectic may be effected by allowing a mixture to solidify partly, and then pouring or squeezing out the melted portion.

The characteristic appearance under high magnifications is that of alternate bands of light and dark material. For example, the eutectic of iron and carbon is composed of *curved bands* of hard cementite standing out in relief, and of soft ferrite forming furrows between them. Mr. Stead points out, however, that the eutectics present themselves under many other forms. The eutectic of silver and lead isolated by Savile Shaw is found to consist of *straight bands.* Sometimes the bands are broken up into dots, the *cellular structure,* as in the case of the eutectic of phosphorus and iron containing 10.2 per cent phosphorus and 89.8 per cent iron. When rapidly cooled, certain eutectics assume a *spherulitic structure,* as in the alloy of lead and antimony, containing 87.3 per cent lead and 12.7 per cent antimony. The two constituents begin to solidify from nuclei, and grow outwards from these, yielding a mass with an appearance resembling that of certain minerals.

When cooled slowly, some eutectics assume *geometric crystalline forms,* which break up internally into the usually banded structure as in the triple alloy, containing 80 per cent lead, 15 per cent antimony, and 5 per cent tin. The eutectic alloy of antimony and copper, Fig. 7, by the different orientation of the alternate hard and soft plates in adjacent masses, also shows signs of the formation of large crystalline grains.

Mr. Stead thinks it probable that the geometric forms are determined by the crystalline habit of the hard constituent, and further research is needed to determine whether there is any disposition on the part of the homogeneous liquid solution to crystallize as a whole, a disposition which is instantly modified as solidification takes place, and the solution breaks up into two solid solutions.

There is, at any rate, no essential reason apparent why the structure of eutectics should be so exceedingly fine ground. Perhaps by heating eutectics to a little below their melting points for long periods of time, the constituents may be more completely separated, and studied with greater convenience.

The study of alloys with the aid of the microscope has made rapid advances in recent years. Fig. 8 is an anti-friction alloy containing 83.3 per cent of tin, 11.1 per cent of antimony and 5.5 per cent of copper. The load is carried by the hard grains which have a low coefficient of friction and are not easily subject to the accidents known as *hot-box* and *cutting* when there is an abrupt and very great increase in the coefficient of friction. When an axle is placed in a new bearing, however, contact between the two takes place only in a small number of points, and if both axle and bearing are hard and unyielding, heating rapidly ensues. To avoid this and to allow for irregular wear, and also for irregularities of adjustment in erecting a shaft carried by several bearings, the matrix of the anti-friction alloy must be soft and plastic so as to mold itself to the axle during the running, and yet must be strong enough to carry the load without permanent distortion.

It is well to add that Behrens and Baucke* do not agree with Charpy. They find the star-like crystals are too brittle to stand much pressure and crumble badly. If, however, the metal is cast at a proper temperature, the fragments worn off are largely spheroids in shape, consisting of worn cubes of the antimony-tin alloy, and these mixing with the oil form a *ball cushion,* so that a rolling instead of a sliding friction is set up.

Surfaces of fusibility.—Lead and antimony form alloys suitable for the bearings of axles, but in general binary alloys are not suitable, and ternary, or even more complex mixtures are employed. In studying these, M. Charpy showed that just as the constitution of binary alloys can be deduced from their curves of fusibility, so that of ternary alloys can be ascertained by the construction of surfaces of fusibility.

Thus, in Fig. 9, the points, *A, B, C,* are the apices of an equilateral triangle, and any point, *M,* inside the triangle corresponds to a particular ternary alloy, the distances from the three sides, the sum of which is constant, representing the proportions of the three metals. If, now, a line is raised from the point, *M,* perpendicular to the plane of the triangle, and its height made proportional to the temperature of fusion of the alloy, and the same procedure is followed for all points inside the triangle, surfaces of fusibility are traced out resembling that shown in Fig. 10.

**Metallographist,* January, 1900, page 4.

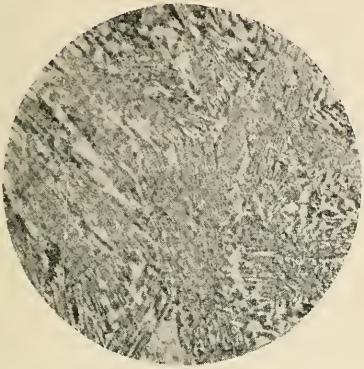


Fig. 7—Eutectic alloys of antimony and copper

Fig. 8—Alloys of tin, antimony and copper, polished and etched

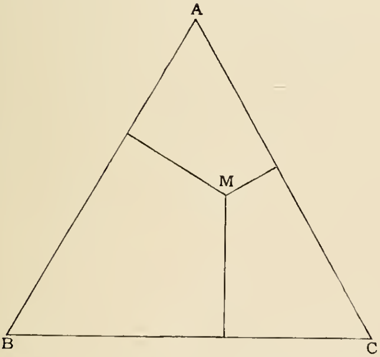


Fig. 9—Constitution of ternary alloys

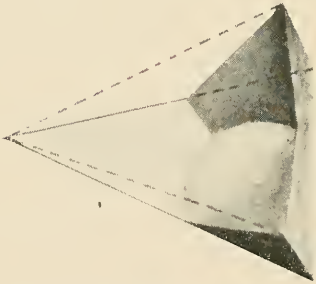


Fig. 10—Surface of fusibility of ternary alloys

IV

SOME DIFFICULTIES OF ALLOYING

THE difficulties in the way of making alloys are many and real. The common difficulties attending most manufacturing processes may generally be overcome by diligent application and the observance of well known laws and conditions, but the combining of metals to form alloys cannot always be regulated by the normal behavior of the individual components. Some knowledge of chemistry and the chemical relations of the elements is absolutely essential to the intelligent handling and treatment of the metals throughout the various stages of manufacture into alloys. But the modern tendency in all manufactures is to reduce the chemistry of the processes to the simplest form so as to make it easy for the unskilled worker to produce correct combinations. In photography, the amateur has at his command a large selection of compressed reagents enabling him to obtain results which for lack of technical knowledge or on account of the expense, he could not otherwise reach. In medicine, too, the physician, by means of tablets is able to relieve his patient of much of that nausea following the use of liquid drugs. And in the metal world the principle of preparing concentrated alloys of metals which, subjected to the ordinary treatment, unite with difficulty, has grown within the last twenty years to be a specialized industry, making it possible for the general founder in alloys to produce economical and reliable combinations of volatile and highly refractory metals.

Alloying by concentrates.—These "tabloid" alloys, if we may so name them, have been a great boon to foundrymen. We all know the danger and uncertainty attending the direct introduction of phosphorus, mercury, magnesium or aluminum, into molten metals at high temperatures. The brass founder has benefited greatly by this new system of alloying by *concentrates*. Copper-manganese, ferro-zinc, aluminized-zinc, phosphor-copper, phosphor-aluminum, phosphor-tin and silicon-copper, in guaranteed proportions, are easily procurable by the foundryman, and they are quite as convenient as prepared reagents are to the practical chemist. Indeed, practical alloying in its modern aspects may justly be described as a higher branch of practical chemistry, where crucibles and furnaces take the place of beakers and Bunsen burners, gases and liquid metals act and react, and the resulting compounds follow unchangeable laws with the same accuracy as we find in laboratory practice.

The reactions of metals on metals in the molten condition are quite as consistent as the reactions of other substances, but up till now they have not been classified.

Metallurgists have been too busy grappling with problems arising out of the physical conditions and relations of the metals to exhibit the chemistry of alloys with anything like fullness. Nevertheless, the subject of metallic reactions is one deserving of the fullest investigation. If foundrymen in their everyday experience have had it demonstrated that the presence of manganese tends to precipitate sulphur in cast iron, the presence of aluminum tends to precipitate lead in brass, the presence of antimony tends to precipitate copper in silver alloys, and additional copper tends to precipitate lead in pot metal mixtures, surely an extended list of such reactions would mark the danger line in certain mixtures and help the founder in alloys to a better and more scientific method.

We can understand then how it is that the method of making an alloy is sometimes rather a vexed question. Recently, much light has been thrown upon the structure of metals, as the following indicates:

It has been shown, for example, that iron and other metals may exist in several distinct (allotropic) forms. In general, all crystaline substances have a non-crystalline form, and the physical properties of the two are usually very unlike. Tenacity is greatly increased by drawing into wire. In the case of soft iron resistance to stretching is thus increased from 20 to 80 tons per square inch. The resistance of gold when drawn into wire increases from 4½ to 14 tons. Silver and copper show an even more marked increase. Until recently, the adjective *crystalline* suggested hardness and brittleness; but in the pure ductile metals it has been shown that the crystalline state is actually the soft state. The *softness* of these metals is in fact due to the instability of the crystalline formation. The non-crystalline state is the more stable mechanically, and therefore the harder. When a metal is hammered to some extent the crystalline structure is broken down, and thus the hardness is increased. The process, however, is never complete. Even in gold leaf beaten to a thickness of 280,000th of an inch there are still minute crystalline units which escape destruction because they are protected by the harder, non-crystalline portions in which they are embedded. Hence, hardened metals are always complex mixtures of crystalline and non-crystalline structures. In the passage from the crystalline to the non-crystalline state there is an intermediate condition in which the molecules appear to have much of the freedom and mobility of the liquid state. If this is suddenly congealed no crystals are formed. The same thing happens in the case of an ordinary liquid when suddenly frozen. A curious evidence of the complex nature of a *pure* metal due to the presence of distinct allotropes of the element, is the fact that wires of hard and soft pure metal act together like a thermo-electric couple of two distinct metals. Another curious fact is that it is not necessary to melt a hardened metal to get it back into the crystalline form. This is restored at far below the melting point. Thus gold again becomes crystalline if heated to 280 degrees Cent., while it does not melt much below 1080 degrees Cent. All that is required is to add just enough kinetic energy to the molecules to enable these to overcome their cohesion; as soon as they can do this, they arrange themselves in the definite form characteristic of their crystals.

In alloying, the chemical qualities of the metals are of the very first importance; and still the general approach to the practical combination of metals is made by experiment and deductions from physical tests. It is here the difficulties in alloying metals begin. We make utility the supreme test of a metal and all our standard metals are the product of extended experiments. These standards are liable to be displaced by later experiments, and the discovery of new methods of combining the metals. In every case the excellence of the later product might have been attained through a closer study of the chemistry of the alloying metals.

Alloys in bronze.—The improvements in bronze due to the introduction of chemical equivalents of phosphorus, manganese, etc., and the superiority of sterro-metal based on the chemical affinity of zinc and iron, afford striking proofs of the advantages of chemical as opposed to the mechanical solution and combining of metals. Of course, in ordinary melting practice, there is always a tendency for the metals in an alloy to cool out according to their specific gravities, and if there is much difference in their melting temperatures, the more fusible metal is apt to liquate after the principal alloy has set. Exceptions, be it noted, are metals which enter into chemical union, or metals which may be freely mixed in all proportions showing always the qualities of a true mixture by the predominance of the physical properties of the metal present in excess. Common examples of the latter are: Copper-zinc alloys, aluminum-zinc alloys, lead-tin alloys, and silver-copper alloys. Such metals present few difficulties in working and perfect casting alloys may be obtained by the direct method, *i. e.,* the more infusible metal is melted first and the desired proportion of the more fusible metal is dissolved therein.

Metals which are liable to liquate out of an alloy require to be constantly stirred while liquid and to insure sound castings they should be remelted, cast at a low temperature and cooled as quickly as possible.

Alloys for castings are only of service when the metals entering into the composition can be made to unite and form homogeneous compounds. It follows, therefore, that the first aim of the workman in making alloys is to unite the metals in such a way that the finished product will retain all the characteristics of a true metal. Many metallic compounds that we know of are utterly useless for any of the purposes of a metal. That the metals have stronger affinities for the non-metallic elements than for other metals is amply proved by the condition of the majority or the ores from which they are derived. In nature, *free* metals are the exception. All metals combine with oxygen, sulphur and certain radicals in proportions, which to a great extent are determined by the temperature and their environments.

Oxidation of metals.—Oxidation is the chief hindrance to the perfect union of metals as alloys, and oxides are the bane of metal mixers. As a rule, the activity of oxygen in combination with fused metals increases with the temperature and also with every additional element present in the alloy. Complex alloys are therefore not so easily manipulated as alloys of two, or perhaps three metals.

The mere surface oxidation of metals is not nearly so harmful as the formation of oxides by metallic reactions, some of which have already been noted.

When the oxides of the constituent metals dissolve in an alloy, or rather, are carried in solution, the resulting metal is always materially decreased in strength, tenacity and homogeneity. The usual precautions against oxidation are not equal to the prevention of a certain loss in melting, but by special treatment, alloys may be prepared free from oxides.

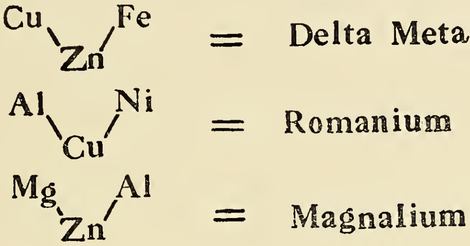
Difficulties of alloying.—The liberal use of suitable fluxes and materials to exclude the access of air is practiced in every brass foundry; and in some cases special precautions are taken to preserve a deoxidizing flame within the furnace. The choice of fluxes for alloys and the part they play in removing impurities and in reviving the fluidity and other properties of the metals, constitutes an important branch of the business of practical alloying,—a branch which demands close reasoning and discernment of the chemistry and the physics of materials. That being so we shall do well to devote a separate chapter to foundry fluxes and their effects. But to return to our *difficulties.* The shrinkage of alloys and their habits of congealing give the brass founder more pause than the mere reduction and blending of the metals.

The rate of melting, the temperature of casting and the rate of cooling are three very important factors in determining the density, grain and soundness of alloys. No metal can be melted without decomposition but the ultimate composition and the physical qualities may be controlled within well known limits. Foundrymen are well aware that some alloys are stronger than others, even when chemical analyses proves them to be identical in composition. This should draw attention to the fact that alloys are extremely sensitive to heat treatment. The effect of high temperatures on metals of low fusibility is always harmful, favoring the absorption of gases, the formation of oxides and inequality of the properties usually associated therewith. It is a common delusion that the metals in an alloy should be melted hot to insure a thorough mixture; it is also a common mistake of some molders to demand hot metal for all kinds of castings. The tyro at mixing alloys frequently blunders because he does not understand the delicate nature of forces nor the susceptibilities of materials in an atmosphere of 2,000 degrees Fahr., or thereabouts. He regards heat as the influence to which all metals must succumb; and he does not seem to be aware that many of the metals may be more easily dissolved in, and more safely and perfectly combined with other metals at lower temperatures than the melting point of the most refractory in the series.

Combustion of the metals is useful in certain refining processes but it is altogether an undesirable incident in alloying. To alloy metals properly one requires to be more than a diligent fireman. For every alloy there is a *proper heat* beyond which it should not be raised, and a *casting temperature* at which the best results are to be obtained. *Proper heats* and *castings temperatures* will some day be standardized and included in the specifications for standard alloys, but it is never safe to predict finality in the methods of their preparation.

It is an axiom in the metal trades that the most refractory component in an alloy should be first reduced to form a bath in which the more fusible metals may be dissolved. This custom dies hard, nevertheless it is doomed. The introduction of intermediate alloys, as ferro-zinc in delta metal, hardening in babbitt metals, and copper-manganese in manganese bronzes, has changed the general practice of combining metals by their solubilities to the more effective chemical methods of modern times.

The most widely diffused metals are not necessarily the most easily reduced or alloyed. Aluminum has always been plentiful but it is only beginning to be a profitable product; iron also is plentiful, but it must be used sparingly in alloys. Many of the metals do not make practical combinations by the ordinary methods of alloying, while others are favorably influenced by the introduction of another element. It sometimes happens that the addition of a third element favors the union of two non-combining metals, thus—



Again, goldsmiths use gold alloyed with copper and silver in preference to the copper hardened or silver hardened metal. The three metals combine to form tough, malleable and ductile alloys of better working qualities than those obtained by using copper or silver alone, as the alloying metal. Copper and lead have a very weak affinity for each other, but alloys of copper and lead are rendered more homogeneous when nickel is added.

Remelting Alloys.—Fortunately, the difficulties arising from impurities in the metals are lessening and today it is not nearly so needful for most requirements if only a portion is remelted. Of course we have to admit that any treatment of a metal which increases its density usually increases the strength also. But as most metals lose in fluidity every time they are remelted, it is recognized that melting a portion of the new metals with the already mixed alloy is advantageous. Some alloys are less fluid at higher temperatures than they are at a moderate heat above the melting point. Aluminum alloys and anti-friction alloys of zinc, copper and tin behave in this way; they are easily overheated and much waste results from careless melting. The microscopical examination of alloys has confirmed the belief that the temperature and melting conditions exert considerable influence on the permeability of the metals. Metals which appeared to be saturated with some particular alloy have, by changes of temperature and melting methods, been made capable of taking up more of the alloy. The variations in the molecular condition of different specimens of the same alloy, are also largely due to variations with melting practice. We have already said metals are now obtainable in comparatively high conditions of purity, but it is not always easy to keep them so, particularly when their fusibilities are unyielding.

The higher the temperature at which a metal becomes fluid the more readily does it occlude gases and absorb impurities; hence the difficulties of alloying increase with the temperature required to reduce and combine the metals. In Cowles' electrical method of producing aluminum bronze, it is assumed that the aluminum and copper unite when both are in the gaseous condition, and by this means "a completeness of union between the constituents of the alloy is obtained, superior to alloys formed in any other way." Here is a method of alloying which awaits development. All metals may be heated until they assume a gaseous condition, but only the records of the patents office reveal to us examples of metallic combinations of this unique order.

The modern practice in alloying metals which are difficult to unite by *direct* method is to present one of the metals in a nascent condition. For example, Dr. Goldschmidt's process of alloying tungsten with aluminum for the production of *wolframinium* is accomplished by adding tungstic oxide to the reducing bath in the manufacture of aluminum. Again, to alloy nickel with aluminum is not an easy matter; rich alloys of the two metals are generally made by adding NiO to a bath of Al.

Up to the present, we can alloy metals of every class and enhance such desirable properties as color, strength, sonorousness, flexibility, etc., but not by rule or rotation. Anomalies occur in the practical processes of alloying which demand special treatment.

The properties of the various metals undergo such diverse changes in the heat and they are so easily influenced by the presence of minute proportions of other bodies that no hard and fast rules can be given for combining them into alloys.

Physical characteristics of alloys.—The iron founder has only to study the fluid characteristics of cast iron, and with ordinary skill in molding he should secure good castings. It is different with the founder in alloys, he strikes new features with every change or addition in the metals. Due to long experience, and the mutual affinity of the metals forming the alloy—brass may be cast with reasonable prospects of good results in the castings; but add another element to it—iron, manganese, aluminum, nickel —and the new combination defies the old experience. Gates, ramming, sand, venting and melting methods all require modification.

In short, the physical properties of alloys depend upon their chemical composition *and also upon the treatments, thermal and mechanical, which they undergo;* so that, to possess the correct formula for an alloy and not to know the correct treatment for the combining metals is like trying to solve a puzzle without the key.

The chemistry of high temperatures and the reactions of metals are at the root of all the changes and troublesome modifications encountered in practical alloying. When this side of metallurgic endeavor is better delineated and better understood, the practical difficulties of alloying will be greatly minimized, at least, so far as alloying with *new* metals is concerned.

Grading by fracture.—Unfortunately there is a growing practice in the various kinds of metal foundries of using mixed metals to produce standard alloys economically. The purchase of these mixed metals or scrap alloys by specification is too ideal for present day consideration, so grading by fracture and color is adopted. It has been borne in upon iron founders that grading by fracture is a lottery; by and by the same idea will penetrate to the brass foundries, the type foundries and the so-called metal refineries. It is admitted that some outlet must be found for old metals, but the miscellaneous scrap heaps of the junk dealer grow more treacherous every year; the values are often fictitious, and nothing short of a remelt and analysis should satisfy anyone desiring to be honest in building up alloys from scrap and mixed metals.

I was once called upon to find a use for about four tons of mixed babbitt and anti-friction metals collected by my predecessors from ships and engines undergoing repairs. With difficulty I persuaded the management to stand the expense of melting down the lot into ingots. Drillings were taken from each ingot and again the drillings were melted for analysis. This showed:

	Per Cent
Tin	55.69
Lead	32.04
Antimony	8.65
Copper	1.95
Iron	0.18
Zinc	1.13
	99.91

Now it should be evident to anyone acquainted with anti-friction metals that this mixture could only have a limited application. By the judicious addition of tin, copper and antimony, a good serviceable bearing metal was produced, and the economy was so great in this instance that the firm afterwards adopted the same method of dealing with brass and gun metal scrap and castings left on their hands by customers. They found it paid better to know just exactly what they were putting into the daily mix. In dealing with old metals an analysis gives the like assistance to the metal mixer that a chart gives to the mariner.

James A. Darling, Philadelphia, claims to have discovered a process for making alloys of copper and iron which are perfectly homogeneous. This process consists in melting copper with a mixture of oxide of iron and calcium carbide, which gives, after being properly treated, the above mentioned alloy. Any oxide of iron, either hematite or the black oxide, can be used. A mixture of three parts of oxide of iron and one part of calcium carbide is made, and, if it is desired to obtain a 50 per cent alloy of copper and iron, 18 parts of this mixture should be used to 8 parts of copper. The copper is melted in a crucible and the mixture added, a little at a time, the bath being stirred and the temperature raised gradually. When the operation is completed, the alloy is poured in ingots or any other desired form.

If an alloy containing as much as 85 per cent of iron is required, the process is reversed, a bath of iron being substituted for the bath of copper, and a mixture of oxide of copper and calcium carbide being added. The inventor claims that, on account of the fact that one of the metals is presented to the other in a nascent condition, a perfect union is formed.

This is an example of making alloys by laboratory methods. For experimental work such methods have their place, but the practical difficulties have still to be met and grappled with by practical means.

V

METHODS OF MAKING ALLOYS

THE importance of method in making alloys can hardly be overestimated. Perhaps there is no industry requiring more constant vigilance, or more careful revision at the different stages of manufacture, than the production of the metallic alloys. Practical metallurgy is concerned with the smelting, refining, and alloying of the metals; these three processes are frequently interdependent, but the climax is reached in the last named, as the behavior of alloys rarely coincides with the behavior of the component metals. Owing to the many valuable properties which certain proportions of the useful metals impart to each other, the manufacture of alloys and the desire for new combinations is not likely to diminish. The advantages to be gained by alloying metals are not confined to any particular branch of metal working, but as the majority of the useful alloys are handled by the brass founders, and we are at present more intimately concerned with the founding of metals, our survey of the manufacturing methods shall follow the routine of the foundries. The methods of preparing alloys now in vogue have been developed within the last 50 years from crude and unreliable forms of procedure into more systematic standards. Nevertheless there is no code of rules for the correct production of alloys. There can be none since the different alloys have to be made, with necessary changes, according to the nature and characteristics of the metals employed. All the metals possess much the same characteristics but in such widely varying degrees that the treatment meted out to those at one end of the scale, would be altogether unsuitable for those at the other end. The nature of an alloy cannot be determined beforehand from our knowledge of the metals.

Metals in the fluid condition obey the laws of fluids. They have a solvent power which generally increases with the temperature, but which is not limited by the fusibility of a solid metal in conjunction therewith. When a molten metal has been saturated with another metal, its power of dissolving the latter may be increased by the addition of a third constituent. When a solid dissolves in a liquid there is a change of temperature due to chemical changes effected by the molecular motions of the two bodies. Thus, in making alloys, heat is sometimes absorbed, but in most cases the reaction is *exothermal,* heat being evolved. Metals which combine with the liberation of heat are in particular well suited for forming alloys.

Alloys may be prepared mechanically by compressing the powders of the metals, and electrically, by depositing the metals by means of a powerful electric current, but the most important method of alloying is by the direct fusion of the metals in a heated atmosphere.

Most metals are capable of existing in some degree of chemical combination with each other, but we know so little of the real nature of chemical affinity that alloys are generally composed experimentally, as mixtures without any special regard to chemical principles. As it has already been shown, alloys were made at first quite unconsciously by the early metal refiners. *Aurichalcum,* i. e., golden copper, was a product of nature, and the secret of its manufacture could never be mislaid. Brass was originally manufactured by the cementation of calamine ($ZnCO_3$) and copper, long before the discovery of zinc in the metallic form. The ancient Greeks acquired such proficiency in preparing this alloy that the demand for Corinthian brass was greatly increased.

Alloying by the Ancients.—But the alchemists were the originators of systematic experiments in the art of alloying; and as they generally dealt with small quantities of the elements they were studying, it was easy for them to fuse the various metals in separate crucibles and bring them together by pouring them into one another. This was the first practical plan adopted by metallurgists for the manufacture of alloys; but as the number of metals entering into alloys increased, it was found more convenient to make a preliminary combination of two or more of the components, and to dissolve that in the metal forming the base of the alloy. We have a survival of this method in the manufacture of anti-friction alloys, *hardening,* in this case, being the name of the preliminary alloy. Bell founders make an alloy of copper and tin in equal proportions, called *temper,* and this is used to harden the copper, and to avoid remelting the whole of the alloy. Brass founders sometimes prepare a *mixing* metal to be used in making up alloys to a required standard. Delta metal is prepared by adding zinc which has been saturated with iron, to molten copper; and phosphor bronze, to be correctly made, requires a preliminary combination of phosphorus and tin, or phosphorus and copper. These are a few examples of the direct fusion methods of making alloys.

Like many other industries, the manufacture of alloys has been surrounded with a great amount of secrecy. The results of alloying processes have been well advertised,—but the processes themselves—not much.

It would seem as if the public needed to be impressed with the unique qualities and trade marks of certain alloys—and patent medicines. It is quite true that the exact composition and the mode of preparation are important matters in producing uniform alloys, and while we may by chemical analysis, be able to determine the exact composition of an alloy, it may not be possible, by ordinary methods, to reproduce the physical properties of the original sample. Many celebrated metals owe their inherent virtues to a particular mode of manufacture. Alloys are sensitive compounds; as a rule they are more easily oxidized than their components, and remelting makes a remarkable difference in their physical conditions. Generally, the proportions of the constituents are changed thus: Alloys containing aluminum, copper and iron, show an increase when remelted, alloys containing zinc, tin, manganese, phosphorus, antimony and bismuth, show a decrease when remelted; alloys containing lead remain stationary when remelted. The difficulty of preparing alloys of definite composition is increased when old metals are combined with new to make an alloy. It is quite possible to build up alloys to any specified standard with scrap or remelted metals, provided the average content of the components is known. But it should always be borne in mind that the chemical analysis of an alloy gives no information as to the method of its production, and the properties of an alloy cannot always be reproduced simply by using the published formula.

The actual capabilities of a metal are seen in the physical tests, and as it is easier to keep to the chemical proportions than to combine the elements in the same physical condition, the best results are obtained by preventing liquidation, oxidation, crystallization, or anything that would interfere with the homogeneity of the alloy. In making sound castings from almost any of the alloys, the metal should not be overheated, and as a general rule, it should be poured when it is sufficiently fluid for the work.

Melting alloys.—Prolonged melting is to be avoided except where the removal of volatile impurities is desirable. Antimony, arsenic, zinc, mercury and bismuth are sometimes removed from alloys by keeping them in a molten state for a prolonged period. Alloys are always more fusible than the mean of their constituents, and their physical properties and chemical behavior alter with every fresh addition. Metals with weak affinity generally show the characteristics of the metal present in largest quantity, and *vice versa.*

It often happens that two competing firms make castings from the same patterns and to the same specification. Both lots analyze within the limits of the specification, but when the castings are put to the physical tests there may be a difference of a ton in the tensile strength or 100 pounds per square inch in hydraulic resistance—all the difference between good and bad castings—in the two lots. This can only be accounted for by the methods of selecting, melting, mixing and casting the metals. It has been understood for a long time now that the presence of a small, nay, almost insignificant quantity of an element may have a far-reaching influence on the properties of a metal or alloy.

Aluminum cannot be used in the highest quality of steel as it induces crystallization. Magnesium, like aluminum, is a powerful reducing agent, generating great heat in forming alloys. It is sometimes added to nickel to remove traces of oxide which may be dissolved in the metal, but if any excess of magnesium is used, it does not alloy with the nickel. In the same way, phosphor bronze—an alloy of copper and tin which has been fluxed with phosphorus—generally in the form of copper phosphide or tin phosphide, may lose its best properties and be rendered worthless by a slight excess of phosphorus. Only when the impurities or foreign metals dissolve freely and become incorporated in the alloy, can the founder afford to ignore them. In many cases the content of foreign elements is so very small that it cannot be reckoned as a factor in the final alloy, except by showing either better or worse results than the alloys which do not contain them.

Pertinent points in alloying.—The main points to be considered in manipulating metals for the purpose of making alloys are the fusibility, volatility, fluidity, and chemical affinity of the combining metals in the heat, and the homogeneity of the alloy in the solid condition. Some metals only combine in limited proportions. Lead is said to be capable of holding about 2 per cent of zinc; copper takes up about 8 per cent lead, and zinc is said to be saturated with iron at 5 per cent. Since aluminum has been added to the brass founders' repertory, the difficulties of alloying have been increased. Aluminum plays havoc with any alloy which contains lead, it has great affinity for silica, therefore sprues or scrap with sand adhering must be thoroughly cleaned. If aluminum gets mixed with soft solders it destroys the adhesive or fluxing properties of the alloy.

Aluminum as a flux.—The indiscriminate use of aluminum in alloys has done great injury to the reputation of the metal as a mixer, and hindered the usefulness of the *bona fide* aluminum alloys, particularly aluminum bronze and aluminum brass. As a deoxidizer, aluminum is a snare and a delusion, for when it comes into contact with the oxide of any other metal, and heat is applied, it displaces the oxygen of the other metal to form oxide of aluminum (Al_2O_3) and the last condition of that metal is worse than the first.

Aluminum brass alloys are correctly made in either of two ways; first by introducing metallic aluminum into molten brass, or second, by introducing zinc into melted aluminum bronze. Repeated remeltings of this, or indeed any of the brass alloys are not advisable, unless allowance is made from time to time for loss due to the volatilization of zinc.

In these days of concentrated products and short cuts to fortune, it is the easiest thing in the world, (if we can believe the story the ad writer tells) to produce alloys in definite proportions with metals which are known to be difficult to combine. Special alloys are manufactured in a highly condensed form to meet the needs of brass founders and to avoid palpable difficulties in the way of reducing and combining elements of widely different qualities. The introduction of ferro-manganese, ferro-aluminum, ferro-zinc, copper-manganese, silicon-copper, aluminized-zinc and phosphorized copper and tin, as intermediary alloys, has reduced the difficulties in connection with the production of complex alloys to a minimum.

Disparity in melting points of metals.—A common difficulty in making alloys is the disparity in the fusibilities of the metals. This is generally overcome in foundry practice by fusing the metal with the highest melting point first and then adding the more fusible elements in the solid condition. With brass, bronze and nearly all the copper alloys, this practice commends itself as giving the most economical and satisfactory results. But with volatile metals in conjunction with highly refractory metals, as, Zn+Fe or Sn+Pt, advantage is taken of the solvent action of a metal of low fusibility when melted in contact with one of high fusibility. If zinc were introduced into molten iron the loss of zinc would be considerable, the ebullition of the iron would be dangerous and the composition of the alloy would not bear the intended proportions.

Whereas, when finely divided iron is mixed with molten zinc, a definite proportion of the iron is absorbed and the two metals combine with ease. Again, platinum is so difficult to fuse as to require the aid of the electric arc or the oxy-hydrogen blowpipe; but if a more fusible metal is reduced to the molten state and small quantities of platinum are gradually added, many useful platinum alloys may be produced. Nickel also is difficult to fuse by itself, but if it is to be alloyed with aluminum or copper as in the German silver alloys, the best practice is to place the metals in the crucible in layers, with powdered charcoal between, and charge in the same manner as brass.

Very often the temperature and the order in which the metals are introduced to each other in the crucible are matters of importance. Alloys containing copper, lead, zinc and tin, are more readily made to specification if the metals are melted in that order and the metal is raised to the proper heat immediately after the last admixture.

Alloys of metals which melt below a red heat may be made by simply fusing the metals together, but combinations of volatile and readily oxidizable elements require more careful treatment. Alloys which enter into chemical combination, in atomic proportions, as $SnCu_3$ may be remelted without undergoing any change in the ratio of the constituents. Unfortunately, very few alloys of practical utility can be made in atomic proportions.

Mr. Parsons, the inventor of manganese bronzes for propellers, claims that the elements in his alloys are combined in atomic proportions. "This renders the alloy much more stable than when not so combined, and if a quantity is passed through an ordinary reverberatory furnace and exposed to the action of an oxidizing flame for a considerable time, no appreciable difference is made in the composition of the alloy." This is an ideal alloy, according to the description, but the real thing has its drawbacks. Like all sluggish metals it gets more sluggish every time it is remelted, and the loss of the *combined* alloy is considerable. Besides, all metals in the molten condition absorb gases, this one included.

In melting crucible steel, the metal, as soon as it becomes liquid, is said to be *clear melted*. If poured at this stage the ingot would be honeycombed with blowholes, due to the gaseous condition of the metal. By raising the temperature and adding small quantities of silicon-spiegel or other substances which are either capable of combining with the gases, or of increasing the solvent action of the steel, sound ingots may be obtained. In all the foregoing examples, it should be observed that crucible melting is implied. The fuel should not come in contact with the metals in making alloys.

Melting anti-friction alloys.—Perhaps no class of alloys have suffered more from careless melting and wrong methods of combining the constituents than the white anti-friction alloys. Anti-friction alloys are based on the low coefficients of friction and high atomic volumes of the components, compatible with certain degrees of fusibility, hardness and wearing qualities. Much depends on the physical structure and condition of these alloys for keeping down friction. They should be close-grained and thoroughly homogeneous. We know that many cheap brands of anti-friction metals are made by melting antimonial lead and small quantities of tin together, and sometimes these compounds are dignified by the name of babbitt metal. Also, it is customary in some quarters, to cast steam fittings from mixtures of scrap brass, scrap copper, and additions of lead or tin to bring them up or down to the standard of the firm making the goods. Scrap has its legitimate use in the making up of alloys but it is not always economical, nor good for building up a reputation.

There are other methods of preparing alloys than by fusing the metals in a crucible or other furnace, but as they have not reached to any extensive application in the arts, we can afford to pass them by. Nevertheless, there still remains many undeveloped theories relating to alloys, many phenomena of metals in conditions of contact, in solution and in solid combinations, to stimulate research and give rise to a better understanding of the science of combining the metallic elements.

Brass foundry melting ratios.—Brass foundry practice relating to the methods of melting and mixing the alloys is a theme deserving the interest of manufacturers and tradesmen alike; nevertheless, statistics and data illustrating the melting ratio of the various alloys, or the methods of dealing with the combining elements in the crucible, furnace, or cupola, are practically *non est.*

The melting methods practiced in various foundries are the natural outcome of different and divergent experiences. The iron founder has devised a system of producing fluid iron in the cupola which he considers unapproachable either in economy or in its effect on the ultimate product; that is, the castings. The brass founder has improvised other means of obtaining the same end, while the steel founder has improved on the brass founder's method to suit the conditions most desirable for the making of steel castings. No sane man would for one minute question the purpose of the several methods which have now become traditional. They are based on rational ideas and long experience in the art of reducing respective metals to the proper fluidity required for running into molds and producing perfect castings.

It is generally acknowledged that the vast amount of independent thought and experimental research which have been accumulated in determining the melting ratio of cast iron in the cupola, have led to a more economical system of cupola practice, as well as to a better understanding of the materials required to produce fluid metal in the best condition suited to the castings to be made. So much must be granted to the leaders in modern iron foundry practice.

By a long course of practice, coke has been established as the ideal fuel for melting cast iron in the cupola, and iron foundries have benefited most by the discussion of the merits of fuels, and the economics of melting iron, for the foundry.

In the brass foundry things are different. Melting records, if they exist, are retained for private use only. Brass founders are the most conservative of foundrymen, they keep tenacious hold of so-called trade secrets to their own detriment, they are biased in favor of obsolete methods, and in many cases they must either be debited with a lack of interest or energy, or else a secret satisfaction with the legacy of their predecessors in the business. No one has yet dared to particularize any one fuel or mixture of fuels as the best for melting brass founders' alloys. It would appear that the ratio of fuel required to melt bronze or brass alloys, or the influence of different fuels on similar metals or alloys, are subjects which have escaped the serious notice of the average brass foundry worker.

The writer has frequently had occasion to melt the standard bronze (copper 90, tin 10) in crucible furnaces with natural and forced draughts, in reverberatory furnaces, and in the cupola, and his experience has proved that some fuels are better adapted to the respective methods of melting than others. For instance, charcoal is the most convenient and economical fuel for crucible furnaces having natural draught; coal is the best fuel for the reverberatory furnace, although the low cost of crude oil has led many manufacturers to consider its application to this class of furnaces; and coke is certainly the fuel best suited for melting in the cupola, the most expensive and uncertain of all the melting methods practised in the brass foundries.

Quick melting, and the process of collecting molten metal on the hearth, are against economy with alloys melting at from 1200 degrees to 1800 degrees Fahr.; besides, in the cupola, the fuel is in contact with the bronze, and gases and impurities are absorbed by the molten metal from the waste products of combustion. While it has been proved that the conditions of melting in the cupola have direct influence on cast iron, either in removing undesirable elements, or in building up the metalloids to a required standard, this quality is a decided hindrance to the successful melting of brass alloys in the cupola. To obtain satisfactory results the pressure of the blast must be lowered and the more fusible metals, tin, lead, zinc, must be mixed in the ladle instead of passing through the cupola to form the alloy. This adds another objection to the practice of melting bronze in the cupola, if the composition, tin, lead, etc., is added to the molten copper when it is tapped out. The resulting alloy is not so homogeneous as when the metals are melted together, as is done in the reverberatory furnace and in crucibles.

When we take into account the great variety of alloys in use, their peculiarities, and the high cost of metals, crucibles, and fuel, to produce them, we can readily understand how it is that no hard and fast rules have been established in brass foundries. Add to this the diversity in the character of the work, the lack of uniformity of methods in foundries producing the same class of work, and the difficulty of securing reliable reports of the amount of fuel used in melting metal, or the relative cost of fuel to metal melted in brass foundries, is at once apparent. For some time I have been taking note of the melting ratio of one alloy (copper 9, tin 1), and also the influence of different fuels and methods of melting on the same. Table IV is the result of several observations and a comparison of many interesting points which may be helpful to the brass founder.

TABLE IV

MELTING RATIOS

	Metal melted, pounds	Method	Fuel	Quantity used, pounds	Loss in melting, per cent	Melting ratio per pound of fuel
1..	400	Crucibles (Natural Draft)	Charcoal	318	0.89	1.25
2..	400	Crucibles (Natural Draft)	Purified Coke	300	1.22	1.33
3..	400	Crucibles (Forced Draft)	Equal to Connellsville Coke	348	2.18	1.12
4..	400	Crucibles (Natural Draft)	Coal	325	1.04	1.20
5..	17305	Cupola	Equal to Connellsville Coke	2184	7.93	7.91
6..	2240	Reverberatory furnace	Coal	1768	3.57	1.26

In all experiments ingot copper and tin were used. Where crucible melting was the method employed, 200-pound crucibles were used and about 3 inches of coke space was allowed all around the crucible. The fuel weights given include kindling the furnace and melting the metal for castings. Test bars were made from each sample, the best results being obtained from No. 2. The bars were turned to ¾-inch diameter. No. 2 gave a tensile test of 19.4 tons per square inch, with an elongation of 16 per cent in 10 inches. No. 5 gave 17.6 tons, with 14 per cent elongation; in this instance the tin was melted in the ladle and the copper was tapped from the cupola on top of that. In another trial, not given in the table, mixed metal was put through the cupola with very inferior results. The loss in melting was 10.14 per cent in a total of 27 cwt., and a test bar similar to those mentioned gave only 14.8 tons tensile strength and 8 per cent elongation.

Coal is recognized to be the most congenial fuel for crucibles, but coke or charcoal is more convenient and more economical. Oil and gas are both preferable to solid fuels for brass melting in reverberatory furnaces, if it can be shown that the quality of the metal produced is equal to that received by the older methods of melting. The heat is easier controlled, the space required for storage of fuel is less, a pipe or a tank taking the place of the coke or coal heap, and the price of fuel per 100 pounds of metal melted is so much cheaper that it behooves brass founders who use reverberatory furnaces to inquire into the merits of some of the modern oil or gas furnaces of that description. If an engineer were confronted with a problem of this kind, he would reduce it in a twinkling to a formula. By means of some abstruse equation in algebra, he would prove that as so many heat units are required to melt a metal, the fuel best suited for the purpose is that which produces the required caloric in the quickest time at the lowest cost. But foundrymen know the uses of arithmetic better than to reverse the order of progress when dealing with purely physical phenomena. It is a remarkable fact that, while the metals have been discovered or confirmed in their characteristics by scientists, the bulk of the useful alloys have been due to the experiments and researches of scientific nondescripts. Babbitt, Muntz, Dick, Parsons, and many other inventors of alloys, were more deeply interested in the practical results than in the scientific effects of their experiments. The work of the Alloys Research Committee and similar bodies has not been the means of profit that it might, because it failed to consider the influence of fuel on metals in ordinary refining or brass foundry processes. In contrast to this, it may be here pointed out that the progress which has been made in the past decade in electro-metallurgy, has developed kindred sciences, notably metallography and crystallography, to such an extent that we are now beginning to understand the defects of the older systems of reducing metals. Pure metal is easier obtained by electrolytic methods than by any other, simply because there is no contamination in the source of heat or energy in the process of separation or combination. The increased demand and manufacture of pure copper and aluminum is largely due to the cheapening of electrical methods for separating the metals from their impurities. The changes which have taken place in metallurgical methods and refining processes indicate the trend towards purity in modern times. And now appears the point of this digression. Of what avail is *pure* metal *melted in contact with impure fuel?* Electrolytically refined copper should produce superior gun metal castings in the foundry, if melted and alloyed under suitable conditions, but if ordinary care and *inferior* fuel are used in the process of reduction, the chances are that G. M. B.'s or the common tough copper would give results equally as good. Pure copper absorbs impurities more readily in the furnace than impure, because the impurities in the latter, which are the result of environment in the raw state, or chemical affinity in the process of refining, tend to repel the further assimilation of extraneous matter. It becomes evident, therefore, that any attempt to reduce the melting ratio in brass foundries to figures must also deal with the final condition of the metal when it has been turned into castings. To sum up, the melting ratio in brass foundries is not a question of economy only; the nature and requirements of the work to be cast, and the effects of the fuel on the metal and the crucibles, or furnaces, are important factors in the ultimate cost and utility of brass founders' castings, and it is an open question whether the association of gold, silver, bismuth, arsenic and nickel in the ingot copper of former days was detrimental to such castings.

VI

COLOR OF ALLOYS

ON a color basis, the useful metals are divisible into three classes, red, white and yellow. Copper, silver and gold may be taken as representative shades in this metallic tri-color. Contrary to the popular idea, the colors that may be obtained by alloying different metals and metalloids are neither numerous nor well defined. The scale of metallic lusters is limited, and it is less under control than the gamut of musical sounds. Nevertheless, the range of tones, harmonies and coloratura is governed by similar principles. Light vibrations and sound vibrations give positive results in color and pitch, and artistic effects follow the interchange of relative tints and tones. But owing to this limited, three-fold battery of metals at our disposal, all our decorative castings come out in shades of copper-red, golden-yellow or silver-white.

These bright colors lend themselves to beautiful contrasts with hammered black iron, polished woods, stones and building materials generally, so that in architecture, chromatic blends delight the eye, and castings are almost equal in importance to any of the other decorative media. John Bunyan was right when he fixed upon *eye-gate* as one of the principal entrances to the human citadel. Color is not only a comforting eye food, it is a stimulant; it is as graceful as spice to the nostrils or sauce to the palate; it encourages the use of ornate expression and dispels dinginess; it gives the human outlook an optimism that would be sadly missed; it turns the dull gray matter of life into a garden and blends in kaleidoscopic beauty, form and feeling in line and curve, distance and the eternal verities. Monochromes, monotones and monosyllables have their uses in the elementary stages of art treatment.

but color values, chords and word pictures are on a higher plane. Thus it happens, where the self color of alloys falls short, the artist in metal work has recourse to surface coloring, staining, bronzing, inlaying, enameling, damascening, electro-plating, japanning, etching and lacquering for the complemental effects and colors.

Decorative processes.—These interesting processes are beyond the scope of this work, but a passing reference might be made to the numerous subtle and permanent decorative results of applying metallic compounds, or of depositing a film of one metal upon the surface of another. The lasting effects of fire gilding and electro-deposition are not to be compared to the temporary exotic decorations which can be put on with a brush and which depend upon varnish to fix them. In the one case there is a true deposit or alloy of metals, in the other, only a stain or film of color. Some time ago Mr. Sherard Cowper-Coles described a new process of blending metals which he discovered when conducting some experiments on the annealing of iron, "that metals in a fine state of division, to a temperature several hundred degrees below their melting point, in contact with a solid metal, volatilize, or give off the vapor that is in the form of a powder, when heated, condenses on the solid metal placed in the powdered metal.

"This discovery has recently been turned to account for the inlaying and ornamenting of metallic surfaces, enabling results to be obtained similar to damascening, but with the additional advantage that there is no risk of the metals finally separating, as is often the case in damascening. The new process also enables a variety of effects to be obtained and a number of metals to be blended together which has hitherto been impossible, and alloys of many colors and tints to be obtained in the one operation of baking. The thickness and depth to which the metals are to be inlaid and onlaid can be controlled at the will of the operator.

"The process consists in coating the article with a stopping-off composition, those portions which are to be inlaid being left exposed. The composition is about the consistency of cheese, so that it can readily be cut with a knife; the design is traced with a sharp edged tool and those portions to be removed are lifted and cleared away. The object thus prepared is placed in an iron box containing the metal which is to be inlaid in a powdered form. If zinc is the metal to be inlaid, zinc dust is the powder that will be employed, which is a product obtained direct from the zinc smelting furnaces. The iron box holding the powdered metal and the objects to be ornamented is then placed in a suitable baking oven and heated to a temperature many degrees below the melting point of zinc, which is 686 degrees Fahr., so that the temperature to which the zinc dust is heated is about 500 degrees Fahr."*

This is really a burning-in process and the metals blended are definitely alloyed and unalterable. A soft transition from the inlaid metal to the surrounding metal is obtained, also some beautiful color effects, the process being applicable to iron, copper, zinc, cobalt, nickel, antimony and aluminum.

Dissolving metals out of alloys.—Another method of obtaining variety in the coloration of metals is to dissolve certain metals, as copper, zinc, aluminum, etc., out of alloys containing them. This may be done with acids, only sweating out a portion of the more fusible metals. Goldsmiths make the changes of color in this way in the manufacture of articles of luxury. The one great drawback to the fixing of color values in metals is the susceptibility of the base metals to atmospheric influences. The metals tarnish quickly, especially in exposed conditions, and so we apply paints and preservatives to check deterioration. Chemical bronzes which produce color effects on metals are simply stains due to chemical reactions between the acids and the metals. Such applications of acidulated washes give various shades with alloys which can be fixed by lacquering, japanning or coating with some inert transparent substance. For example, the very antique looking green bronze of the art dealers' ware is obtained by alternate applications of dilute acetic acid and the fumes of ammonia on common brass articles.

Mechanical color effects.—Peculiar mechanical color effects are sometimes obtained by electro-plating a bar or ingot of soft metal with a film of harder metal and then rolling or pressing the bar or ingot into a sheet or other shape of larger area. By this spreading action the hard surface deposit is broken into irregular forms and a marbleized appearance is produced. Again, metals may have colors impregnated by firing articles coated with certain pigments in a muffle furnace. Some metals are capable of form-

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ing volatile compounds at comparatively low temperatures, especially in the presence of reducing gases, and these volatile compounds will penetrate the surface of other metals, giving a characteristic stain of a permanent nature.

Tinning is another method of coloration, although as a rule, articles are tinned with quite another object in view. By dipping the heated article in a bath of molten alloy—many other metals besides tin may be used in this way—exposed parts acquire color from the metal in the bath.

Colors of alloys.—Coming to alloys for castings, some of the color changes produced by mixing various metals will now be noted. But first let it be understood that such alloys, besides beauty of color, must possess certain stable qualities which will make them suitable for working up and turning into articles of a strong, useful character. The color of alloys is modified in greater degree by metals in the following order, according to Ledebur: Tin, nickel, aluminum, manganese, iron, copper, zinc, lead, antimony, platinum, silver, gold.

Thus an alloy of one part tin and two parts copper is white, but nearly two parts of zinc must be added to one of copper to whiten it and more remarkable still, one part of aluminum has a positive effect on nine parts of gold, this alloy being a comparatively soft white metal. Common yellow brass is a blend of red and white metals, the strongest alloy in this class being copper 63 parts, and zinc 37 parts, the color being full yellow with a copper content varying anywhere between 60 and 75 per cent. The copper color is not thoroughly saturated until zinc reaches 60 per cent, and beyond that quantity the increase of zinc has a decided zincy white effect.

For dipping brass, the best results are produced with alloys of copper and zinc only, preferably with zinc ranging from 20 to 30 per cent. Sometimes tin in small proportions is added, but if more than 1 per cent is used, a greenish hue is given to the yellow of the brass, and if crystallization of the tin occurs, a nasty mottled appearance is given to the work when it is dipped. However, where the work is partly polished, tin adds brilliance. A good mix of this kind contains copper 72.5, zinc 27, tin 0.5. On the other hand, lead, while it facilitates machining, darkens the color, and when the articles are dipped, cloudy streaks betray the trail of the base metal. The effects of other elements foreign to the true copper and zinc dipping mixtures are mostly fatal to the gilt-like beauty of fine yellow brass fresh from the dip or acid bath. By fine yellow brass, an alloy containing not less than 70 per cent copper is generally understood. Red brass ranges in copper from 80 to 90 per cent, with 1 per cent of lead in addition, if the work is to be machined.

Colors of Bronze or Gun Metals.—Bronze or gun metals, the chief constituents of which are copper and tin, have rich, deep hues that may be graded from red and reddish yellow to grayish white, according to the tin content. Tin, from 3 to 9 per cent, gives reddish shades, and increasing this element from 10 to 14 per cent, orange and yellow shades appear; at 18 to 23 per cent a creamy white luster describes the polish of finished parts and a beautiful oxidized silver appearance is given to the rough castings. Very few foundrymen seem to realize the difficulties in controlling shades or intensity of color in consecutive heats of the same alloy. Owing to the volatile and oxidizable nature of the average components and the varying effects of different temperatures and rates of cooling on the alloys, the color of the castings from two or more heats of a particular alloy do not always match. These mismatches of color are more readily detected in polished work, hence we have another reason for the use of tinted lacquers, namely, to impart a uniform tint to the color of the work. This question of the color of castings is a very important feature in some branches of brass founding, and in the arts.

Architectural and decorative brass founders are continually confronted with this color problem. When two castings of the same alloy do not match it offends good taste to see them placed side by side on a job. Uniformity of color can only be insured by adhering to the exact composition of the alloy, by using always the same brands of ingot metals, by melting under the same conditions; and by casting at the same temperatures. To emphasize the importance of the last mentioned condition, let me cite a case. A casting which had been partly machined developed a flaw. The defective part was burned with a spare metal left over after making the casting and yet, when it was finished, the burned part was distinctly visible, owing to the marked difference in the color at that part. In fact, it had what you might call local color, a very undesirable quality in a casting, however agreeable it may be in novels or art products. The coloring action of some common elements used in alloys is worthy of study. Some of the general effects are indicated, in so far as they affect the copper series.

Color action of metals in alloys.—Lead deepens the color of copper alloys. It is largely used to assist the copper in red metals and also to give gun metal a more coppery appearance than the actual copper content alone would produce.

Zinc improves the casting qualities of copper alloys, but has quite the opposite effect on the color that lead has.

Aluminum gives a mottled surface due to crystallization of that element. One per cent added to yellow brass produces a good imitation of pale gold.

Phosphorus, by closing the grain, allows of a higher polish on all alloys.

Arsenic has a similar effect, but it is now only used for speculum.

Bismuth and manganese produce rose-tinted effects and improve the luster. Bismuth has a powerful effect on all the white colored metals, giving a warm tone to German silver alloys containing zinc, tin or aluminum.

Antimony has a similar result as regards color, but it is a dangerous element in alloys requiring strength. The cohesive force of antimony is poor.

Copper added to white alloys gives increased luster, greater ease in tooling and better casting qualities.

Mercury, about 1 to 1.5 per cent, added to the standard ordnance bronze, (copper 90, tin 10,) produces a beautiful rose-pink-tinted metal which makes fine contrasts with other gun metal, brass or silveroid castings. Great care must be exercised in adding the mercury to the barely molten tin intended for the bronze mixture.

Venus metal, an alloy of equal parts of copper and antimony, brittle for delicate parts of a design.

An alloy used for objects of art and which resembles fine gold, consists of copper 92 parts, aluminum 6 parts, gold 2 parts.

Non-oxidizable alloys generally have nickel as a base and platinum as an ingredient. Two mixtures of this class follow:

No. 1—Nickel 90 parts, tin 9 parts, platinum 1 part.

No. 2—Nickel 34 parts, brass 66 parts, platinum 3 parts; platinum black may be used.

Owing to its high cost, platinum is not much used for alloys for casting, but manganese is sometimes used as a substitute.

Alloy for statuary bronze.—An alloy recommended by Brantt for statuary bronzes and objects of art for outdoor positions which admits of simple treatment by washing with pyrosulphides, chlorides, etc., and becomes coated with a rich black patina capable of being polished, consists of copper 77 parts, tin 6 parts, lead 17 parts. This alloy also lends itself to some fine contrasts with silveroid, the tones of these two metals being easily controlled and ranging from the fine gray appearance of matte silver to the velvet black enamel of the genuine patina, with intermediate shades of gold and burnished silver in relief.

Niello-silver, an alloy consisting of copper 1 part, bismuth 1 part, lead 1 part, and silver 9 parts, and which is filled into the incised lines of metal engraving, acquires a bluish color when a little sulphur is added.

A cheap imitation silver alloy consists of zinc 76 per cent, copper 17.5 per cent, and nickel 6.5 per cent. The foregoing alloys are selected with the object of illustrating some of the novelties and the limitations of the color scale in metallic productions.

Japanese pickling solutions.—The Japanese art metal workers, who understand the coloring of metals better than we do, obtain different colors by employing ores or metals with traces of gold, cobalt, antimony, tin, silver, etc., for the alloys, and using pickling solutions in which they boil the work. Two of these pickling solutions, given by Prof. Roberts-Austen, contain the following ingredients:

	No. 1	No. 2
Verdigris, grains	438	220
Sulphate of copper, grains	292	540
Water, gallons	1	1
Vinegar, drachms	...	5

The various colors and tints are the result of differences in the length of immersion and the effects of impurities in the ores or of definite additions to the alloys. As soon as the articles assume the desired shade or density they are dried, heated and lacquered. By making complex alloys containing traces of cobalt, antimony, bismuth and other metals, iridescent colors are obtained. One objection to these surface colorations is that the film may be scratched and the self color of the alloy revealed.

The striking points regarding the color of alloys may be summed up as follows:

First.—That all the known metallic alloys are limited in color to shades of red, white and yellow.

Second.—The alloying of metals for color effects has not received the attention it deserves. We know that certain metals produce sudden color reactions, as in the examples given, where small additions of aluminum in gold, tin in copper, and nickel in copper show radical changes.

Third.—Alloys are mostly blends as regards color of the metals, which behave like neutral solutions, the color of the alloy being dominated by the color of the metal present in larger proportion.

Fourth.—Pigments of every hue may be produced from metallic bases, but the metals are in a state of combination with the metalloids, in equivalents which destroy completely their metallic character and luster.

Fifth.—The discovery of some system of controlling or imparting color in alloys would be a novel and, unquestionably, a useful achievement, but for casting purposes only self colors are suitable, and if a new color of alloy is to receive notice, it must have a consistent tone and beauty that is more than skin deep.

VII

THE NOTATION OF ALLOYS

THE notation in common use for distinguishing the various metallurgic products is, for the most part, a promiscuous growth of popular or local characterizations, private marks and industrial apothegms. The quality of the useful metals, iron, copper, tin, zinc, etc., is generally indicated by the brands or grade numbers of the manufacturers. These markings may be useful in commercial quarters for fixing a basis price in each class, but in the actual founding of metals they are of no practical value. Such marks as *"best," "best best," "treble best," "tough"* and *"G. M. B.'s"* (good merchantable brands) are supposed to give the buyer a clue to the quality of metals, but in reality they only indicate the relative qualities of the productions of each individual maker. The *"best best"* of one maker may be no better than the *"best"* of another; and the analyses of *"best selected"* copper ingots, "virgin" zinc, or "refined" tin, varies with the mines and the extraction processes from which they are evolved. The marking of metals, then, fixes no standard of quality; the crowns and crosses, the lions and the lambs which are impressed on them, are used for the same reason as "3 stars" are adopted for certain brandies,—for advertising purposes. But something more than a trade mark or a market brand is needed to guide the purchaser of alloys; therefore, it is becoming the custom to stipulate the percentage of the principal elements contained in modern alloys. For instance, by *genuine* babbitt metal, an alloy containing not less than 80 per cent of tin is understood, and in brass foundry parlance, *yellow metal* signifies a copper and zinc alloy in which the proportion of zinc does not exceed one-third of the mixture. Vocabularies are made up of names, numerals and *nuances;* but the vocabulary of the metal trades is notorious for its numerous inappropriate names, meaningless signs and misleading catch-words. The ceremony of bestowing a name upon anything is always regarded as being of great importance. Babies and ships are *christened,* churches are *consecrated,* hospitals are *dedicated,* memorials are *erected,* patents are *granted* and territories are *claimed* and *proclaimed* only when the initial ceremony of naming has been accomplished. Whatever formalities may take place at these occasions, the general interest is centered in the name which is bestowed. A name should, as nearly as possible, focus the purport or the properties of the object named.

There is much to be learned from names, when they are properly applied, but a misnomer is always a snare to the tyro and a worry to the scientist. "What's in a name?" is as difficult a question to settle as—"What's without a name?" One cannot give utterance to a thought or single out one thing from every other thing, until he has invested it with a suitable appellation. The metal trade is handicapped by having two sets of terms—the commercial and the scientific—to distinguish the goods, and in the matter of alloys, or mixed metals, the long list of oracular, informal and arbitrary titles which have been adopted within the last half century, has got beyond the capacity of the average metal worker. The beauty of chemical nomenclature is, that it always supplies accurate information. It is qualitative and quantitive, for it tells the nature of a compound and also the proportions of its elements; H_2SO_4 is a definite substance to the chemist. When he sees the familiar formula, he not only thinks of sulphuric acid, but, instinctively, he makes a mental note of the order and relationship of the constituents. How different is the system by which the metallic alloys are formulated. Granted that the alloys which form true chemical compounds are comparatively few, there is no reason why the components and proportions of even the most intricate alloys should not be graphically stated.

Chemical notation can only be applied to alloys when the metals combine in atomic proportions to form chemical compounds, and it would be difficult for metallurgists to devise a systematic nomenclature for alloys with anything like the simplicity and comprehensiveness of the chemical method of designating salts, etc. We long, however, for some more rational method of naming alloys than the happy-go-lucky system now in vogue. The bewildering array of names, which are allowed to be applied to alloys which are the same in substance, is a disgrace to an industry based on scientific principles. Metallurgy is probably the most comprehensive of applied sciences and the names given to the metals belong to all ages and countries. Whatever name has been chosen for a metal, the Latin form of it has been generally adopted for technical purposes. If metallurgists could devise a similar system for naming the metallic alloys, they would bring order out of chaos, make it easier to marshal the mixed metals into groups, and less difficult to understand what are the essential elements in any particular class of alloys.

Confusion of present notation.—Uniformity is the life of science, but there is no uniformity in the metallic hurly-burly. Alloys are seldom what they are represented to be. Gun metal for ordnance is obsolete, but the name survives. Phosphor bronze, which was originally an alloy of copper, tin and phosphorus, has been modified and altered beyond recognition as a bronze. Copper and lead are frequently the principal components of so-called phosphor bronzes, the phosphide of tin being conspicuous for its scarcity. Platinoid is a high resistance (electrical) alloy, which is innocent of platinum. Aluminum bronze as it is now made, is not the unique alloy which promised so well some years ago; a pinchback variety has supplanted the genuine alloy, but, to avoid confusion, it should be called aluminum brass. It is in reality ordinary brass, containing from 1 to 2 per cent aluminum. Examples of this sort of thing could be multiplied *ad libitum.* The metals have been named in all sorts of ways. The alchemists fancied some metals male, others female. Arsenic is derived from the Greek word for male. Some of the metals are named after gods, goddesses and stars, as, *Titan*-ium, *Thor*-ium, *Mercury,* etc.; others derive their names from the countries in which they were first discovered—*Cuprum,* (Cypress), *Germanium, Gallium,* but the origin of names for alloys is too obscure for elucidation. Sometimes an alloy is named after its inventor, as Muntz metal; sometimes after the inventor's initial, as Delta, the Greek letter beginning the name of Mr. Dick; sometimes the inventor disguises his identity and the nature of the alloy by a latin suffix, as "Partinium;" sometimes by a figurative title, as "Atlas" bronze, "Glacier" metal, etc. But the most common names for alloys have been illustrative of the uses for which they are suited. Such names as, anti-friction metal, steam metal, button metal, type metal, fusible metal, convey to the metal worker a general idea of the properties of the respective alloys. But none of these metals has been standardized and every manufacturer makes them according to his own impression of the requirements. Again, alloys are usually classified according to their densities, or by their most important or predominant constituent, as copper alloys, aluminum alloys (light and heavy), tin alloys, etc. In many instances the names and the classification are at variance. White metal, for example, may mean a copper alloy containing zinc and nickel, or it may mean a tin or zinc alloy for bearings or patterns. Anti-friction alloys are known to the trade by these amongst many other titles: *babbitt* metal, *bearing* metal, *fusible* metal, *patent* metal, *plastic* metal, *white* metal and *anti-attrition* metal. Again, take German silver alloys: In addition to the standard compositions in use in industrial countries for the manufacture of tableware and coins, known as German silver and nickel alloys, respectively, the brass founder recognizes a host of other products in the same class, under a grotesque variety of names, as *albata, argitan, argusoid, silveroid, silverette, packfong, biddery,* etc.

These examples serve to show how ambiguous the names conferred on alloys may be; how contradictory, how unnecessary; but they by no means exhaust the terms descriptive of anti-friction or German silver alloys. The dictionaries and technical and classical literature have been ransacked by makers and advertisers of alloys for names for their wares. Hundreds of catchy, high-sounding names have been registered; and there is quite a flood of superfluous appellations to be dispelled before anything like a systematic nomenclature, or notation of alloys, can be unfolded.

Systematic notation.—Chemists formulate chemical compounds by the symbols of the elements present and by their atomic relations, the latter being indicated by the numerals attached to the symbols. This system is not suited for the majority of the alloys, because they rarely combine to form true chemical compounds, and the complex nature of some allotropic compounds would give rise to irregularities. What *practical* metallurgists need is a systematic notation for alloys even if they are mechanical mixtures, *based on the proportions of the components.* This would embrace all possible compounds of elementary substances and include that large and important class of scientifically nondescrip compounds termed the metallic alloys. There is too much mystery about alloys altogether; they are enveloped in scientific fog and manufactured in accordance with the tenets of some secret societies. I submit that there is as much need for an *Alloys Act,* as there is for a *Food and Drugs Act,* in our legislative administrations, since human lives are sometimes dependent on the quality of metals.

The cue to the construction of a notation for alloys is contained in the statement already made, namely, that most of the useful alloys do not enter into true chemical combination, but are simply mixtures of metals which have the power of cohesion at ordinary temperatures.

Atomic formulæ can only be used for *dual alloys which form perfect compounds,* as, for example: Ag_3Cu_2 or $SnCu_3$; but it rarely happens that these chemical alloys of two metals are of any practical value in the arts. Many of the most useful alloys contain three or four elements which are essential to their composition, therefore a system of linking the symbols and the ratios of the contents is required to explain these complications. To follow the chemical usage and connect figures to the symbols would be confusing and altogether an erroneous proceeding. Such figures would indicate chemical equivalents where they did not exist. To get over the difficulty and for the sake of euphony, the first syllable of the technical name of each metal contained in the alloy could be taken to form a composite word which would give a clear and unmistakable intimation of the components. In this way brass would be represented by Cu-Zi, and if the exact amount of each element should be known, the parts could be indicated by figures thus, $Cu_{67}Zi_{33}$. Further, if the brass contained lead, as in cock metal, the formula would become Cu-Zi-Plum, or if it contained tin, as in naval brass, it would be Cu-Zi-Stan; with aluminum or any of the earthy metals or metalloids, the first place would be assigned to the least metallic element, as, Phos-Cu-Stan (phosphor bronze), Al-Cu-Zi (aluminum brass), etc. This notation may not be based on science, but it would be eminently practical in manufacturing circles. It would become a kind of metallurgic shorthand for alloys and the metal worker could then understand the composition and get a general idea of the properties of the material at a

TABLE V

SYSTEMATIC NOTATION FOR ALLOYS

Name	Composition	Proposed Formula
Bell metal	Copper 80 parts, tin 20 parts	Cu-Stan (80. 20.)
Gun metal	Copper 88 parts, tin 10 parts, zinc 2 parts	Cu-Stan-Zi (88. 10. 2.)
Steam metal	Copper 86 parts, tin 6 parts, zinc 6 parts, lead 2 parts	Cu-Stan-Zi-Plum (86. 6. 6. 2.)
Yellow metal	Copper 70 parts, zinc 30 parts	Cu-Zi (70. 30.)
German silver	Copper 50 parts, zinc 25 parts, nickel 25 parts	Cu-Zi-Nick (50. 25. 25.)
Plumbers' solder	Lead 2 parts, tin 1 part	Plum-Stan (2. 1.)
Bearing bronze	Copper 80 parts, tin 10 parts, lead 9 parts, phosphorus 1 part	Phos-Cu-Stan-Plum (1. 80. 10. 9.)
Type metal	Lead 80 parts, antimony 20 parts	Plum-Stib (80. 20.)
Silicon bronze	Copper 90 parts, tin 8 parts, silicon 2 parts	Sil-Cu-Stan (2. 90. 8.)

glance. Table V gives some examples of standard formulæ for comparison.

There should be a limit to the adulteration of structural alloys; there is no limit to the adulterations in the so-called gun metals today. Gun metal may consist of any old thing with metallic luster and a reddish yellow skin. A proper notation of the alloy such as I have outlined here would cure this and similar evils and help lift the metal casting trades out of the "mixture muddle."

VIII

STANDARD ALLOYS

WHEN standard alloys are mentioned, one naturally thinks of the metals which enter into the currency of the country, the formulae for the gold, silver, copper and nickel coinages. The standards of the mint are based on the exchange values of the metals employed, the alloys being for the most part compounded of two metals, the less valuable being added in proportions required to cover the cost of manufacture and the wear and tear of circulation. Consequently, the coinage alloys are easily adjusted. Not so the standard alloys adapted for the production of castings. The standard metals of the mint or the rolling mill are ill-suited for the severer test of the melting furnace; as a rule they are too *rich* for foundry purposes. Foundrymen are well aware that it is easier to make more perfect castings from some alloys than from others; and the nearer an alloy approaches the condition of a *simple* metal the more difficult it is to procure sound castings from it. Imperfections due to occluded gases, oxides, crystallization, shrinkage, etc., must be reduced to a minimum in alloys which are intended for castings more especially when such castings are required for structural or mechanical purposes. Thus it is that dual alloys have gone out of favor in the foundry and the bulk of the modern standard brass founders' alloys are compounded of three or more metals. The monetary value of the metals used for such alloys is of no technical importance; what does matter is the purity of the metals employed. Electrically deposited metals are, therefore, preferable for alloys which have to conform to specification or to attain a given physical standard. Modern investigations have placed the distinguishing properties of some highly useful alloys on an independent platform, and we recognize them as the best in their class—standard metals giving advantages in strength, cohesion and service. Fifty years ago it would have been possible to have classified the more important casting alloys into two groups—brass and bronze alloys, but now we must add at least three distinct series which have taken root in foundry and engineering practice. I refer to the high-tension alloys, the anti-friction alloys and the light (chiefly aluminum) alloys of modern invention. Brass and bronze (copper-zinc and copper-tin alloys) were the forerunners of all the casting alloys, but in these days we have to distinguish between numerous kinds of *high* and *low* brass (these expressions refer to the zinc content), white and yellow brass, naval brass, malleable brass, aluminum brass and many other kinds deriving their names from the introduction of metals foreign to ordinary brass. The same thing applies to the intricate and widely varying bronzes of the present day. The term *bronze* was formerly employed to indicate an alloy, the chief constituents of which were copper and tin, the copper being always predominant, but in recent years almost every combination of metals possessing strength and toughness may be described as bronze. Some notable examples are aluminum bronze, which does not contain tin; white navy bronze with only two per cent copper, and some of Fontainemoreau's bronzes having neither copper nor tin in their composition. As it would be quite impossible to give here in detail the data relating to all the mixed metals qualified for classification as standard alloys, we shall confine our attention to those metals countenanced by engineering bodies, narrowing down the list to such alloys as are suitable for the production of castings in the foundry. While cast iron and cast steel might justly be classed with other standard alloys, it would be inconsistent to discuss these products, considering how thoroughly they have been examined already.

Foremost among the useful alloys we place brass, the simplest and most reliable compound from which castings may be made. Brass, in trade circles, is generally understood to mean an alloy of two-thirds copper and one-third zinc. But in everyday foundry practice, brass may, and does contain other elements besides copper and zinc, and the copper content may vary from 60 to 88 per cent of the mixture, the 60 per cent standard being known as Muntz metal and the 88 per cent standard being what is termed red brass. Between these two limits practically all the useful casting alloys are to be found. The mechanical qualities and physical properties of the brass alloys vary greatly, and, with the exception of color, none of the characteristics produced by alloying copper and zinc may be deducted from a comparison of the properties of the respective metals. Small variations in the composition and different methods of manufacture sometimes effect great changes. For example, the difference in the tenacity of cast brass and cast Delta metal is very marked, as shown in Table VI.

TABLE VI

Alloy, cast	Composition					Tensile strength, tons per square inch	Authority
	Copper	Zinc	Iron	Lead	Phosphorus		
Brass	2	1	....	....	.....	12.25	Dr. Anderson
Fine brass	75	25	....	....	.....	13.1	Mallet
Muntz metal	59	40	....	....	.....	19.0	P. Longmuir
Delta metal	55.10	43.47	1.08	0.10	0.10	23.0	Roberts-Austen
Sterro metal	55.00	42.36	1.77	....	0.83	27.0	Baron Rosthorn

These examples are selected because they represent a fair average for each particular alloy. Many higher and lower results have been recorded, but in every case the chemical combination of iron in a brass alloy results in increased tenacity and hardness. This is probably due to the difference in molecular construction and the greater density of properly made copper-zinc-iron alloys. While brass is essentially a mixture of copper and zinc, within well defined limits, slight additions of other metals are purposely made to facilitate mechanical and manufacturing processes. Table VII embraces most of the mixtures of practical importance.

TABLE VII
Brass Alloys for Castings

Name	Composition				Tested or Adopted by	Suitable for	Remarks
	Copper	Zinc	Lead	Tin			
Red brass.........	85 to 90	10 to 15	......	......	....	Gilding alloys	Zinc content is regulated by thickness and temperature required
Brazing brass......	80 to 90	10 to 20	......	......	Marine surveyors	Flanges, saddles	
Fine brass.........	75 to 78	22 to 25	......	......	....	Florentine bronzes	
Dipping brass......	72	27	......	1	English firms	Ornamental castings	Tin adds brilliancy
Malleable brass....	70	30	......	......	Bolley	Bolts, hinges	
Naval brass.......I	70	29	......	1	British admiralty	Stanchions, etc.	Tenacity, 30,000 pounds per square in.
Naval brass......II	62	37	......	1	British admiralty	Spindles, pump rods	Farquharson's alloy
Yellow brass.......	67	32	0.5	0.5	Gas and water corporations	Taps, unions, etc.	Test pressure, 300 pounds square in.
Yellow brass.......	67	32	......	1	Railway and shipping corporations	Polished brass work	
Yellow brass.......	66	34	......	......	Commercial standard	Ordinary castings	
Yellow brass.......	63	37	......	......	Commercial standard	Second quality	
Turnery brass.....I	66	33	1	......	Birmingham brass firms	General quality	
Turnery brass....II	64	33	0.5	2.5	Shipbuilders	Force pumps, etc.	
Turnery brass...III	60	42	1	......	French standard	Bolts, nuts, etc.	To be remelted
Muntz metal......	56 to 63	44 to 37	......	......	Muntz's patent	Ship fastenings	For soft Muntz add 3 per cent lead
High brass........I	52	48	......	......	Hiorns	Lock escutcheons, etc.	English
High brass......II	50	50	......	......	Bolley	Panels and art castings	German
Brazing solder.....	48 to 52	42 to 52	......	......	Commercial standard	Slabs for pulverizing	A little lead, tin or silver is sometimes added for specific purposes
White brass.......	43	57	......	......	Hiorns	Art castings	
White brass.......	20	80	......	......	....	Art castings	

Phosphorus is frequently added to brass alloys for the purpose of increasing the fluidity. The same object can generally be obtained by remelting about one-third turnings with two-thirds of the alloy, fluxing with sawdust and potash. Aluminum and manganese, alloyed with brass, form two series of metals now classed with high tension bronze.

German silver alloys.—German silver may be reckoned as nickeliferous brass, copper, zinc and nickel being the essential components. The proportions vary, as under, copper 52 to 60 parts, zinc 28 to 32 parts, nickel 8 to 20 parts.

In order to determine the best proportions for alloys containing 8, 10, 12, 16 and 20 per cent respectively of nickel, Hiorns made numerous experiments and finally recommended the following:

I.—Copper 62, zinc 30, nickel 8.
II.—Copper 60, zinc 30, nickel 10.
III.—Copper 57, zinc 31, nickel 12.
IV.—Copper 54, zinc 30, nickel 16.
V.—Copper 52, zinc 28, nickel 30.

Very few of the German silver alloys employed for castings contain more than 20 per cent of nickel, but the better classes of work are generally made by adding one-third nickel to two-thirds ordinary brass (2 and 1 alloy) and lead up to two per cent of the total mixture. The standard metal for electrical resistance is composed of copper 4 parts, zinc 1 part, nickel 2 parts. Another alloy of this description called "manganin," contains copper 84 per cent, manganese 12 per cent, nickel 4 per cent. The presence of impurities in these alloys diminishes their value for electrical purposes. All the German silver alloys are noted for their brilliant lustre, malleability and hardness. Krupp and other authorities are agreed that tin is injurious in this alloy, both as to color and malleability, but iron, up to 2 per cent, increases the effects of these properties. In foundry practice, those alloys containing about 30 per cent of zinc and traces of lead and iron, produce the soundest castings, but alloys containing iron are not adapted for articles of art which are to be exposed to the weather, because they acquire a disagreeable color.

Range of bronze alloys.—As previously stated, the bronze alloys are much more comprehensive now than formerly. The bronzes proper (copper-tin series) comprise many metals of insuperable qualities. The wide range of properties obtainable by combining these two metals has no parallel in the metal industries. Of all the useful alloys, we could least afford to dispense with this series. Standard bronze alloys contain tin in proportions, varying from 1 in 4 to 1 in 12. Three well-known grades take prominence here, gun bronze, which contains copper 89 to 92 per cent, tin 8 to 11 per cent; bearing bronze, which contains copper 82 to 88 per cent, tin 12 to 18 per cent, and bell metal, which contains copper 78 to 86 per cent, tin 14 to 22 per cent. The preparation of these alloys is based on the idea of rendering copper stronger, harder, more sonorous and easy to cast. And just as the addition of lead is advantageous in German silver cast work, zinc or phosphorus in small quantities improves some of the bronzes. Hence, many modifications and additions to the original bronze alloys, giving greater strength, resilience, homogeneity and improved frictional and anti-corrosive qualities, have been adopted in engineering practice. Some examples are given in Table VIII.

TABLE VIII

Modern Bronze Alloys

	Name	Composition					Suitable for
	Gun Metal	Copper	Tin	Zinc	Lead	Phosphorus	
1.	"	88	10	2	—	—	Steam metal
2.	"	87	8	5	—	—	Propellers, etc.
3.	"	88	11	1	—	—	Lighthouse frames
4.	"	86.5	13	—	—	0.5	Hydraulic pipes
5.	"	*87.5	6.25	6.25	—	—	Bolts
6.	"	85 to 95	4 to 10	—	1 to 5	—	Chemical pumps
7.	"	84 to 90	6 to 10	4 to 8	2 to 4	—	Steam metal
8.	"	84	12	4	—	—	Bearings
9.	"	82	14	—	4	—	Mill brasses
10.	"	80	10	—	9 to 10	0.25 to 1	Locomotive brasses
11.	"	88 to 92	8 to 12	—	—	0.25 to 0.5	Deoxidized bronze*

Nos. 1, 2 and 3. Specified by British Admiralty.
No. 4. Specified by French Admiralty.
No. 5. Specified for N. British Lighthouses.
No. 6. Specified by mining corporations.
No. 7. Specified by American manufacturers.
No. 8. Specified by marine engineers.
No. 9. Specified by Colonial Sugar Co., Sydney.
No. 10. Specified by Pennsylvania Railroad Co.
No. 11. C9. T1. = Tenacity, 19.3 tons sq. in.

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*Tensile strength 14.7 tons per sq. in.; elongation 23 per cent in 10 inches (dry sand casting).

Phosphor bronze.—Bronze of any description is such a variable quantity in these days that it is difficult to fix a limit to the components or the proportions of the components. Phosphor bronze in the early stages of its career was simply an ordnance bronze with the addition of from 0.25 to 1 per cent phosphorus, a decided novelty in the manufacture and character of bronzes at the time of its introduction.

Experience and experiments have wrought many changes in the original formula for phosphor bronze—changes not *all* for the better by any means. We have learned that the very best use we can make of phosphorus in alloying is to use it as a deoxidizer, or as a re-agent which will combine with some of the undesirable or weakening elements in certain alloys. And the less phosphorus there is in the finished metal, the stronger and denser the alloy will be, so that phosphorus is a thing one can easily have too much of when making alloys. For foundry purposes the use of phosphor-tin (5 per cent phosphorus) or phosphor-copper (10 per cent phosphorus) is recommended as the most reliable method of getting phosphorus into ordinary brass founders' alloys. The most prominent characteristic of phosphorus in alloys is the marvelous amount of fluidity it yields; its most beneficial effect is probably that it lowers the co-efficient of friction of most metals. Phosphor bronze was the pioneer of the modern bronzes (high tension alloys and anti-friction and anti-corrosive metals), which have led to the free development of power in machinery and revolutionized the art of engineering within the last thirty years. A common error in foundry practice with phosphor bronze is pouring the metal at too high a temperature. This alloy sets so rapidly that occluded gases, always present in overheated metal, have not sufficient time to escape and the result is usually a porous, or at least a very much weaker casting than would be expected.

Peculiarities of phosphor bronze.—Phosphor bronze is a peculiar metal to work with. It is readily spoiled by overheating, prolonged or repeated melting or the presence of certain impurities. The best results are undoubtedly had with dry sand molds, but with care in manipulating the metal, uniformly good work can be obtained in green sand, provided the castings are not above medium weight. Some 40 years ago the introduction of phosphor bronze as a commercial product initiated several new features in engineering. It soon became a formidable rival to steel for many purposes. Phosphor bronze was the forerunner of the modern non-corrosive, high-tension and anti-friction alloys, and even if it has been in some measure, superseded by later discoveries, the history of its uses and advantages over ordinary bronze would still be full of interest and instruction to the brass founder.

As the introduction of phosphor matches marked a decided advance on the flint and steel period of human progress, so did phosphor bronze, in its pristine purity, mark an epoch in the progress of the mechanical industries. When phosphor bronze was first introduced into the foundries, the molders did not understand the nature of the alloy and its best qualities were often destroyed through improper treatment. In spite of the very precise instructions issued with the metal, so many flagrant abuses were common in the foundries that the Phosphor Bronze Co., of Great Britain, to protect its products, and insure fair conditions for its products, was compelled to adopt a method of selling the metal by contract, in which it stipulated that the contracting brass founder should bind himself to use it in a particular way (dry sand molds were preferred and feeders were considered desirable), and to cast it at a particular temperature, the casting heat being judged by the color of the molten metal and the condition of the *break*. I can remember having one or two secrets in this connection imparted to me when I was an apprentice. I have learned a few more since then, but I am one who looks upon all trade practices as *open secrets*.

Brass founders are conversant with the old style of making phosphor bronze with stick phosphorus, which has been steeped in a solution of copper sulphate, dried and enclosed in a tube and then gingerly inserted into the crucible containing the molten bronze. Very few brass founders are foolish enough to practice this primitive and uncertain method now that phosphor-tin and phosphor-copper, containing any desired percentage of phosphorus, may be had at reasonable prices.

The metalloids are beginning to play an important part in the refining and alloying of brass founders' alloys, but there is still much to be done in the way of experiment and research. Phosphorus, silicon and arsenic bronzes are simply modifications of the ancient metal of the bronze age. We have not had the limits of these elements defined, nor a full statement of the properties conferred on metallic bodies by these non-metallic substances. It is expected that the electric furnace will yet solve many enigmas in the reduction of highly refractory or volatile metals, and in the manufacture of alloys. The improvements which have been made already in reducing aluminum and in refining zinc point in that direction.

The effect of phosphorus on the physical qualities of cast iron has always been thoroughly understood, but it is not generally known that phosphorus increases corrosion as well as induces *red-shortness*. The properties and peculiarities of phosphorus when combined with steel, copper, bronze and babbitt metal are not so generally known as they might be.

Suggestions for melting phosphor bronze.—The following suggestions should help to impress on brass founders and others, the right use of phosphorus in this connection:

Phosphor bronze is best melted in a crucible. When it is reduced to the molten condition in a brick-lined furnace, the phosphorus attacks the silica in the lining, forming a slag which increases the waste both of metal and furnace lining.

Phosphor bronze shows a perfectly smooth surface on the ingot, and a characteristic granulation in the fracture. When molten it is easily distinguished by its fluidity, mirror-like surface and the continuous *break* of the fluid metal until it sets.

Phosphor bronze does not assume a pasty condition just before setting. It passes suddenly from the fluid to the solid condition at a certain temperature. Many castings have been cast *short* owing to the metal being cooled too much and allowing it to freeze to the sides of the ladle while casting.

Phosphor bronze castings should not be dipped while still hot to blow the cores out. The phosphorus in the alloy renders it *red-short*.

If you wish to see honeycombs all over the castings when they are machined, pour your phosphor bronze *hot, into unslicked green sand molds*. Many molders do this sort of thing and blame the bronze. The casting cleaner knows whom to blame.

The best phosphor bronze does not necessarily contain the largest percentage of phosphorus. Phosphorus beyond the quantity required to produce homogeneous metal weakers the castings.

Phosphorus is a powerful deoxidizer, but an excess may create a worse evil than oxide. The recognized limit for cast iron is 1 per cent, for bronze 3 per cent; the less phosphorus there is in the finished metal the greater the resiliency of the bronze.

In steel of 1/30 of one per cent phosphorus would render the metal valueless for edged tools.

Phosphorus introduced into ordinary bronze increases liquation and the tendency to segregation.

Phosphorus makes copper hard and *more* liable to corrosion, but added to bronze—copper and tin alloy—*less* liable to corrosion.

Phosphorus in bronze increases the grip of the patina or surface oxidation, so much sought after in ornamental bronzes.

Phosphorus, in conjunction with zinc in a gun metal alloy, increases the co-efficient of friction; in conjunction with lead it reduces friction considerably. Kunzel was the first to deprecate the use of zinc in phosphor bronze. He patented an alloy which is now recognized as a splendid anti-friction metal for locomotive and other bearings liable to heat.

Phosphorus has great affinity for iron and acts to chemically combine brass and iron. This fact is largely taken advantage of by brass refiners to neutralize the bad effect of iron upon brass. For example, in refining borings, ashes or washings, which always contain iron, phosphorus is the agent which is commonly used to get the two metals, brass and iron, to amalgamate.

Phosphorus increases fluidity and fusibility and renders molten metal very limpid. On this account it is often introduced where delicate ornamental castings are required. Sometimes even in fine yellow brass work.

Phosphorus prevents blistering in babbitt metals and improves the anti-friction qualities of the metal.

If you tap a heat of gun metal before it is up to the proper heat, 0.5 per cent phosphorus will help to make it fluid, but it will not do what time and fuel would have done. It is a great mistake for brass founders to rely upon phosphorus as a cure-all for dull metal simply because it helps to run the casting.

Castings in phosphor bronze never suffer from *cold-shut.* Work your sand accordingly and you will be right.

When you wish to introduce phosphorus into the metal, don't wrap a piece in paper and make an exhibition of your agility in evading fireworks. A piece of phosphor-copper will do the work much better.

Gun metal—Nowadays gun metal is a term of great latitude, and it is quite possible to make gun metal, which will satisfy the most urgent demands of engineering, with an admixture of zinc and lead. The British Admiralty do not countenance the use of lead in gun metal alloys, but America is not so conservative, and it has been the common practice there to introduce a small proportion of the base metal into gun metal alloys intended for high steam pressures. The wisdom of this procedure was questioned for a long time, but experience has amply proved the fact that it is quite possible to produce with copper, tin, zinc and lead, a close-grained metal, which will cast well, machine easily, and withstand the highest pressures required in modern steam boiler mountings. Steam metal is the characteristic name given to this alloy; the average mixtures contain copper from 85 to 90 per cent, tin 4 to 8 per cent, zinc 4 to 6 per cent, and lead 1 to 3 per cent, a typical alloy being, copper 87, tin 6, zinc 5, lead 2.

Anti-acid metal.—Another metal in which lead plays a most important part is known as *anti-acid metal.* It is well known that nearly all acids, and for that matter, alkalies, too, dissolve or corrode metals and alloys at ordinary temperatures, and with an increase of temperature this corrosive action is generally accelerated. By many of the newer metallurgical methods the products are obtained by the wet process, from solutions of the ores in the presence of acids. The gain in by-products is considerable, and the time and outlay required to reduce a given quantity of metal is generally less than by the old roasting methods.

This was brought under my notice in conducting a series of experiments for an Australian copper mining plant. The water ends of pumps and machines through which the concentrated solutions of copper sulphate had to pass were made in the first instance, from a special anti-acid metal composed of copper 63 per cent, lead 30 per cent, antimony 7 per cent. This proved a very satisfactory alloy for the purpose, but some of the parts which were subject to friction or stresses, such as the plunger, or the ram, gave out in a short time, and to improve the wearing qualities of these parts, a new alloy was made, containing copper 70 per cent, lead 20 per cent, antimony 7 per cent, tin 3 per cent. Even this mixture did not give complete satisfaction, the conditions were severe and exacting—vibration, continuous working, and heavy load—and after one other trial with a modification of the last alloy, the engineers fell back upon a gun metal containing lead, which has proved useful in bearings and frictional parts of machinery. This mixture consists of copper 85 parts, tin 10 parts, lead 5 parts. Absolutely the best alloy for anti-acid castings is antimonial lead, containing lead, 85 parts, and antimony, 15 parts. Printers' type metal is in this class, but for machinery, slow motion and light loads are essential conditions if this metal is used.

Iridio-platinum.—There are no products of human skill on which a greater degree of care is expended than the standards of weight and measure in use among the civilized nations of the globe. Two things in particular have to be considered: accuracy and durability. Nature does not furnish any single metal, or mineral, which exactly answers the requirements for a standard of measure or weight that shall be, as nearly as possible, unalterable.

The best substance yet produced for this purpose is an alloy of 90 per cent of platinum with 10 per cent of iridium. This is called iridio-platinum, and is the substance of which the metric standards prepared by the International Committee on Weights and Measures is composed. It is hard, is less affected by heat than any pure metal, is practically non-oxidizable, and can be finely engraved. In fact, the lines on the standard meters are hardly visible to the naked eye, yet they are smooth, sharp and accurate.

Aluminum.—In some ways aluminum is a wonderful metal, but foundrymen are chary of using it freely in alloys because of the troubles which frequently follow, such as segregation, porousness, cracks, excessive shrinkage, and the difficulty of making satisfactory combinations with some of the other metals in everyday use for castings. There is a limit to the amount which some metals will take up in alloying.

According to Dr. Richards, aluminum can hold a little over 1 per cent of lead in solution, and from personal experience with aluminum bronze (copper and aluminum mixtures), I have been forced to the conclusion that a very small percentage of lead exerts a very injurious influence on the physical properties of this alloy.

Aluminum for alloys.—Similarly, if aluminum is to be introduced for any special purpose into ordinary gun metal, yellow brass or German silver alloys, great care must be taken to use metals entirely free from lead, otherwise unreliable castings will result. The castings as taken from the mold may appear to be sound, but when the skin is broken on the lathe, a patchy appearance, due to the segregation of the lead and the formation of oxides in the molten metal, shows up the weakness and irregularities of a bad mixture. On this account, all metals containing aluminum should be kept scrupulously apart from the ordinary alloys used in the brass foundry.

The fact is, with all our modern improvements and cheapening processes for the increased production of aluminum, we are not yet familiar with the use of the metal as a mixer, and foundrymen are still seeking for information as to the proper use of it in alloys.

Zinc and aluminum.—Zinc has been found to be the most natural alloying metal for aluminum. Indeed, the two metals may be combined in any proportions almost as freely as the brass (copper-zinc), alloys, and with casting qualities equally as good. As a general rule, however, alloys of aluminum with another metal, binary alloys, are seldom satisfactory for castings, and many mixtures which are serviceable for rolling, hammering, or otherwise working into shape, are utterly useless for foundry purposes. Silver and aluminum, copper and aluminum, and zinc and aluminum are decidedly the best of the binary alloys for castings.

Nickel-aluminum alloys.*—Nickel aluminum alloys have poor mechanical properties and they are difficult to make. Tin-aluminum alloys are unstable and weak and magnesium-aluminum, the lightest of all the aluminum alloys, casts badly and is subject to great waste and change on remelting. Where cost is not a factor and fine grain, color, polish and resistance to corrosion are important, the silver-aluminum alloys are by far the best for ornamental castings, statuettes, etc., from 3 to 5 per cent silver being the average proportions. Sometimes 1 per cent of copper is added to reduce the cost, or to insure better wear as in the case of cast dental plates and fine instruments. The atomic weight of silver is exactly four times that of aluminum and their specific gravities are in the same ratio. It is believed that this has some connection with the characteristic improvement in color, grain and resistance to corrosion, which silver-aluminum alloys show.

Imitation silver.—Many imitation silvers and so-called Argentan alloys are now produced with aluminum as the base. The aluminum content ranges from 88 to 94 per cent and the alloying metals, copper, tin and nickel, are present in equal proportions, varying from 2 to 4 per cent. Cowles' "silver bronze" is also a substitute for German silver, but its electrical resistance is about forty times greater. Although there is no nickel in the composition, it is more closely allied to the standard German silver alloys than those having aluminum as the base. The mixture consists of manganese, 18 parts; aluminum, 1¼ parts; silicon, ¼ part; zinc, 13 parts, and copper, 67½ parts.

Aluminum bronze.—The very first aluminum alloy to come into prominence was the now famous, but seldom used, aluminum

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*Nickelumen is the name now given to alloys of those two metals.

bronze, containing copper 90 to 95 per cent, and aluminum, 5 to 10 per cent. This is an ordinary heavy bronze, with the tin replaced by aluminum. It is a superior alloy to tin bronze, having all the advantages in double the tensile strength, greater resilience, more artistic appearance and color, no segregation or hard spots, better resistance to corroding influences, and, owing to the cheapening of aluminum, the cost by weight is now slightly less. This alloy has never had a chance to distinguish itself in engineering practice. Brass founders have not treated it fairly. They still persist in varying the formula, and add zinc, tin, lead or some other ingredient to cheapen the product with the result that aluminum bronze has fallen into disrepute, and aluminum brass has been substituted for the bronze for many purposes. To those looking for a first-class bronze, giving strong homogeneous castings, no better mixture can be recommended than the following: Copper, 90 parts; aluminum, 8 parts, and phosphor copper, 2 parts.

Some modifications of this bronze are made by adding tin to the mixture, from 2 to 8 per cent, according to the degree of hardness required. A good mixture for bearings is composed of copper, 95 parts; aluminum, 5 parts, and tin, 8 parts. For a close-grained bronze suitable for machine parts and steam metals, use copper, 90 parts; phosphor copper, 2 parts; tin, 4 parts, and aluminum, 4 parts.

Gun metal alloys.—An improved series of gun metal alloys containing aluminum consists of copper, 84 to 88 per cent; tin, 6 to 10 per cent, and aluminum, 2 to 6 per cent. The hardest of these mixtures is suitable for bells and equal to cast steel in strength. It must always be borne in mind, however, that metal made simply by mixing aluminum and copper does not acquire its best properties till it has been remelted several times. For all of these aluminum bronze alloys it will be best to make a "hardening" of the copper and aluminum, say 50 parts of each.

Melt the copper first, and add the aluminum gradually, taking care to keep the metal in a barely molten state. This alloy is very brittle. It is an easy matter, therefore, to add any desired quantity of aluminum to the bronze. As molten aluminum alloys oxidize more rapidly than most of the regular casting metals, it is well to cover the metal with carbon, and a plumbago crucible lid kept on while the metal is melting helps to prevent drossing due to the access of air. No flux is necessary. Aluminum is an earthy metal, and anything that would flux it would act also on the crucible, to the detriment of the metal. Overheating must be avoided, and when once the metal is ready it must not be held in the fire.

With these precautions, and ordinary care not to mix metals of a different class with the aluminum bronzes, sound castings are as easily obtained as with ordinary bronze alloys. A specially tough bronze has the following composition: Copper, 87 parts; tin, 10 parts; nickel, 1½ parts; and aluminum, 1½ parts.

Aluminum brass alloys.—Passing to the aluminum brass alloys, we get a big range of metals with splendid casting qualities and wonderful strength and toughness. Ordinary yellow brass—copper, 70; zinc, 30 (no lead)—with 2 per cent aluminum added, is transformed to a high tension bronze. This metal may be used for almost every conceivable casting, from the lightest ornament to a ship's propeller wheel. Valves, bearings and frictional parts of machines are excepted.

Aluminum brass is the easiest of the ternary alloys to manipulate. The three metals combine well in proportions ranging as follows: Copper, 56 to 80 parts; zinc, 20 to 42 parts; aluminum, one to six parts. The tenacity of the alloys varies between 40,000 pounds and 90,000 pounds per square inch.

Other metals are sometimes added with good effect, notably manganese, between 1 and 2 per cent; iron and phosphorus, about 1 per cent; tin, 1 to 3 per cent.

To the brass founder accustomed to the pouring of "high" brass, aluminum brass presents no difficulty, and this may be one of the reasons for its popularity. Due to the comparatively low specific gravity of aluminum, ordinary heavy metals in combination with it are liable to segregate when cooling down to a solid condition and further, the high specific heat, contraction and atomic volume, characteristic of the metal, make it difficult to get serviceable combinations. These are the main drawbacks to the working of the binary alloys, like the copper-aluminum bronzes already dealt with, but with the ternary alloys, such drawbacks, to a large extent, vanish. Nevertheless, each class has its own points of excellence, and whether it be the bronze or the brass that is used, the artistic as well as the useful and economic value of the alloys should be considered.

Light alloys.—The light alloys of aluminum are more numerous and generally speaking, more applicable to the modern craze for light fittings for automobiles, motor boats, scientific apparatus and art metal castings. Classed with the light alloys are several combinations of rare metals, or metals requiring extremely high tempertures for their reduction, as chromium, tungsten, titanium, etc. These are scarcely worth the increased cost and trouble, and certainly they are not necessary for ordinary castings. Used with copper and nickel, manganese makes the hardest light alloy of aluminum yet produced.

Susini alloys.—Susini's alloys contain from 3 to 10 per cent of alloying metals, the latter being zinc, copper and manganese. He makes the alloy of the three latter separately, melts the required quantity of aluminum and then pours the liquid alloy into it.

The three alloys he recommends must contain in percentages:

Manganese	Copper	Zinc
1 to 3	1.5	0.5
1 to 5	2.5	1.0
2 to 8	4.5	1.5

Good casting alloys for small figures and art designs may be had with tin and nickel combinations, as for example, tin, 7 parts; nickel, 3 parts, and aluminum, 90 parts. This alloy is whiter than aluminum and can be more easily soldered and polished and gives very sharp outline and detail in sand castings.

Nickel alloys.—A stronger series are the ternary alloys of nickel, copper and aluminum, nickelumen alloys, as they are sometimes called, have a great tenacity and a high elastic limit. A typical alloy in this class for rolling contains copper, 3½ per cent, and nickel 1½ per cent. For casting purposes the alloying metals may be increased up to 10 per cent with advantage, and for rigid alloys the nickel content may even be increased beyond the copper.

An excellent substitute for these nickelumen alloys is composed of aluminum, 91 parts; antimony, 1 part, and phosphor copper, 8 parts. An alloy whose specific gravity is nearly the same as pure aluminum, is composed of aluminum, 96 per cent; antimony, 2 per cent, and phosphorus, 2 per cent. These alloys are not so expensive to make as the nickelumen or magnalium alloys and they answer quite as well for many kinds of castings.

Magnalium alloys.—All magnalium alloys (aluminum and 1 to 10 per cent magnesium), are improved by the addition of zinc, 1 to 20 per cent, and there is better wear in the metal, which is more homogeneous. For rolling, nickel and copper take the place of zinc in some magnalium mixtures. One of these mixtures shows aluminum, 96 parts; magnesium, 2 parts; nickel, 1 part, and copper, 1 part.

Cheapest aluminum alloys.—After all, the cheapest and most reliable of all the aluminum alloys for castings are zinc-aluminum mixtures, with possibly small additions of copper, phosphorus or tin. These alloys are well adapted for pattern metals. They may be melted and cast by the ordinary foundry methods, without the slightest trouble. The average composition shows aluminum, 80 to 90 parts; copper, 1 to 6 parts; zinc, 5 to 20 parts; phosphorus, 1 to 2 parts, and tin, 1 to 5 parts. A typical alloy in this class is aluminum, 88 parts; zinc, 10 parts, and phosphor copper, 2 parts. If tin is desired in the mixture, phosphor tin may take the place of all or part of the phosphor copper.

These alloys cast smoother and with less oxidation than most other aluminum combinations, and the zinc cheapens the product without destroying the desirable qualities.

Aluminum bell metal.—A special aluminum bell metal alloy, which may also be used for electrical instruments and ornamental wares, consists of the following: Aluminum, 70 to 90 per cent; manganese, 5 to 18 per cent; cadmium, 2 to 12 per cent. This alloy casts well and takes a brilliant polish.

Was it aluminum?—An incident in Roman history, well authenticated, would seem to indicate that aluminum, instead of being new, may be only a re-discovery of an old process.

It is related by Pliny that during the reign of the Emperor Tiberius, a certain worker in metals appeared at the palace, and showed a beautiful cup made of a brilliant white metal that shone like silver. In presenting it to the Emperor, the artificer purposely dropped it. The goblet was so bruised by the fall that it seemed hopelessly injured, but the workman took his hammer, and in the presence of the court speedily repaired the damage. It was evident that the metal was not silver, although almost as brilliant. It was more durable and much lighter.

The Emperor, so runs the story, questioned the man, and learned that he had extracted the metal from an argillaceous earth—probably the clay known to modern chemists as alumina. Tiberius then asked if anyone besides the worker knew of the process, and received the proud reply that the secret was known only to the speaker and to Jupiter.

The answer was fatal. The Emperor had reflected that if it was possible to obtain such a metal from so common a substance as clay, the value of gold and silver would be reduced, and he determined to avert such a catastrophe. He caused the workshops of the discoverer to be destroyed, and the luckless artificer himself to be decapitated, so that his secret might perish with him. It is possible that the cruelty of Tiberius deprived the world for centuries of the use of the valuable metal—aluminum.

Aluminum bronzes.—Aluminum forms some very valuable alloys with copper, which may take the place of ordinary bronze, phosphor bronze, or steel in certain circumstances. The amount of aluminum in the bronzes varies from 2½ to 10 per cent. The 10 per cent bronze is said to be a true alloy; it does not liquate, and the components remain in the same ratio, however often it may be recast. It is worth noting that the combination of aluminum with metals of higher melting temperatures—copper, iron, nickel—produces *exothermic* reaction, heat being evolved. The metals thus alloyed are more homogeneous, stronger, less liable to oxidization, more fluid and easy to cast. The 7½ per cent bronze is a good metal for general foundry work, and specially suitable for ship fittings, gears and gongs. Aluminum and its alloys should be carefully separated from the ordinary brass founders' alloys, as the smallest portion in alloys containing lead and in certain combinations of tin and antimony produces segregation and increases the affinity of such alloys for oxygen to such an extent as to make it difficult to obtain sound castings. Many of the difficulties of handling aluminum in the brass foundry would disappear if attention were given to this feature, and the melting practice. All aluminum alloys should be remelted; they should be melted *speedily* and cast at the lowest temperature compatible with sharp, uniform castings. Experience has taught those accustomed to handling aluminum bronze alloys the importance of using only the best grades of copper and aluminum, and also the necessity of avoiding, as far as possible, the disturbing influences of a third element.

Light aluminum alloys.—Most of the so-called aluminum castings being put into motors and electrical machine parts are made from alloys containing copper 4 to 10 per cent, or zinc 8 to 30 per cent. Zinc forms a cheap and efficient hardener and in quantities up to 15 per cent it combines to increase the rigidity and strength of aluminum. Tin, as an alloy with aluminum, seems to develop brittleness. Sheets composed of equal parts of the two metals roll easily when the alloy is newly made, but become as brittle as glass in a few days' time. Antimony up to three per cent combines with aluminum to form some useful alloys. The addition of nickel to aluminum produces unstable alloys—an alloy containing 4 per cent nickel crumbling to powder

TABLE IX

ALUMINUM ALLOYS FOR CASTINGS

Aluminum per cent	Nickel per cent	Tin per cent	Copper per cent	Antimony per cent	Tungsten per cent	Remarks
98.04	....	0.105	0.375	1.442	0.038	"Wolframinium"
						Analysis by Minet
96	....	0.16	0.64	2.4	0.8	"Partinium"
97	1.75	0.19	0.25	0.25	0.17	by Dr. Richards
				Zinc	Magnesium	"Romanium"
100	....	....	....	1 to 20	1 to 10	"Magnalium"
					Phosphorus	Murman's patent
96 to 98	....	....	....	1 to 2	1 to 4	Ruebel's patent
						*"Meteorite"
97	0.5	....	1 to 2	0.5	....	Tenacity 11 tons, sq. in.
98	1	....	1	....	....	Extension 5 per cent
96	3	....	1	....	....	Tough
94	2	....	4	....	....	Easily tooled
87	3	10	....	....	....	Malleable
84.21	...	10.23	5.51	....	0.09	Hard, strong
				Silver		Mock silver castings
95 to 98	...	....	....	2 to 5	....	
				Zinc		Aluminum silver
80	....	....	5	15	....	Rigid alloy

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*Non-corrosive, acid-proof and easily soldered or plated, specific gravity, 2.6 to 2.8.

in a few hours after it is cast. Here the introduction of a third element is advantageous, tin and copper being suitable for casting alloys. Some examples used for castings are given in Table IX.

Aluminum brass.—Aluminum brass is perhaps the most popular of all the aluminum alloys. It is easy to manipulate provided lead and antimony are absent, and castings of great strength and brilliancy may be obtained by simply adding zinc to aluminum bronze, or aluminum to ordinary brass. The average alloys contain copper, 55 to 67 per cent; zinc, 28 to 48 per cent; aluminum, 1 to 3 per cent. An analysis of a propeller blade, made by a leading company, gave the following result: Copper 66.95 per cent; zinc, 29.60 per cent; aluminum, 1.93 per cent; iron, 0.97 per cent, and lead, 0.48 per cent. The tenacity of this specimen was equal to 60,000 pounds per square inch, and the elongation about 16 per cent in 10 inches.

Manganese bronze propellers.—Manganese bronze is recognized to be the metal par excellence for ship propellers. Its chief characteristics are, great transverse strength, toughness, hardness and fine casting qualities. P. M. Parsons, the inventor of this alloy, introduced a *cupro-ferro-manganese* into the ordinary brass and bronze alloys and obtained a wonderful increase in the desirable physical properties of the metals, in the case of bronze the tenacity showing an increase of 60 per cent. An alloy, the approximate composition of which is copper, 58 per cent; zinc, 40 per cent; manganese, 1 per cent; aluminum, 1 per cent, gives, in cast ingots, a tensile strength of 72,000 to 76,000 pounds per square inch, with 20 to 22 per cent elongation. It is stated that a properly designed screw propeller in this metal will come much lighter and give as much as half a knot increase of speed, as compared with an iron or steel propeller, this being due to re-

ANALYSES OF PARSONS MANGANESE BRONZES

Sheet metal		Ingots for sand casting	
	Per Cent		Per Cent
Copper	60.27	Copper	56.11
Zinc	37.52	Zinc	41.34
Iron	1.41	Iron	1.30
Tin	0.75	Tin	0.75
Manganese	0.10	Aluminum	0.47
Lead	0.01	Manganese	0.01
		Lead	0.02

duced scantlings, smoother surface, etc., and the evils of corrosion are entirely overcome. Without a doubt manganese bronze is second to none for propeller work. Manganese is a reliable deoxidizer to use in foundry brass and gun metal alloys; in some ways it is preferable to phosphorus. The latter induces cold shortness, and the slightest excess is harmful. Manganese, however, may be used freely, from 1 to 6 per cent of cupro-manganese showing increased tensile strength and elongation.

Anti-Friction metals.—The so-called anti-friction alloys, originally introduced by Isaac Babbitt, have grown to be quite a formidable class, indispensable to the engineer in these days of high speeds and heavy loads. These white anti-friction metals are used almost exclusively for bearings, and they have replaced many of the hard bronze bearing alloys formerly used in machinery running at high speed or under great pressure. The introduction of new metals and alloys has wrought extensive changes and many wonderful improvements in engineering practice. The high tension bronzes already mentioned have raised the capacity and reduced the factors of safety in materials of construction. The modern demand for metals, which shall be light in weight, pretty in appearance, not too expensive and easily worked into shape, has been met by manufacturers and inventors in the later combinations of aluminum, but of all the modern alloys, babbitt metal, under whatever name it may appear, has proved to be the most useful and economical for machine parts in motion. Genuine babbitt metal is composed of tin, 86 per cent; antimony, 12 per cent, and copper, 4 per cent, but numerous alloys laying claim to superior qualities, producing less friction, requiring less lubrication and possessing greater durability, are

TABLE X

COMMERCIAL BABBITT METALS

Tin per cent	Antimony per cent	Lead per cent	Copper per cent	Zinc per cent	
78.56	11.8	6	3.8	.....	
34.74	17.1	44.25	3.92	.....	Arsenic, trace
64.7	....	1	1.8	33.35	
83.26	9.74	0.86	5.50	Bismuth 0.32	Iron, trace
1.25	20.12	78.28	Iron 0.7	0.28	

now on the market. Analyses of five different brands are given in Table X.

The British admiralty uses alloys in this class ranging in tin from 83 to 85 per cent, antimony 7½ to 12 per cent, copper 5 to 9 per cent. The utility of lead in alloys for bearings is now generally recognized, and these analyses go to show that the manufacturers of anti-friction metals are not slow to take this advantage. Standard alloys, or alloys subject to tests, may only be expected to give satisfaction when the best materials have been fairly treated. This is probably the most important feature in the manufacture of anti-friction alloys. To summarize briefly the merits of the metals used in making these alloys, lead is the ideal metal for reducing friction, antimony is the ideal hardener, zinc is the best wearing material and tin is the best medium for combining all of these qualities.

The history of the so-called anti-friction alloys reflects the history of modern engineering, in miniature. In the days when the world and all its works went to the tune of "slow and sure," hot journals and squeaking axles were the signals for a halt; in the present day such untoward happenings are inexcusable. The market is glutted with anti-friction goods —metals, greases, oils, etc., and the plurality of "best anti-friction compounds" in these lines is, to say the least, embarrassing. It has always been an axiom in engineering that rubbing surfaces should be composed of dissimilar materials, in order to economize power and reduce the wear due to friction. Under the heading of anti-friction alloys we must embrace two great classes of metals, bearing bronzes and the white anti-friction alloys. The latter series is by far the most important to the general engineer, but we will deal first, and somewhat briefly, with the hard bearing bronzes favored by millwright and locomotive makers from the early days of machine construction. "Brasses," that is, bronze bearings, differ but little in composition from ordinary bronzes, but they are supposed to offer little frictional resistance when in contact with other metals. The best alloys in this group are characterized by hardness and strength; these qualities combined in a metal are found to resist wear, sustain pressure, and survive shocks. The standard bearing bronzes range in copper from 82 to 88 per cent, tin 12 to 18 per cent. These hard bronzes are still used by many prominent railway companies for axle boxes, truck bushes, slide valves, etc., but the investigations of recent years may truly be said to have disillusioned engineers regarding the old popular fallacy, that bearings should be made of the hardest mixture possible. In the early days of locomotive construction, bearings were purposely made of an alloy harder than the steel or iron in the axle, crank shaft or journal. A mixture akin to bell metal—copper 84 per cent, tin 16 per cent,—was termed "Box Metal," and faithfully used to cast axle boxes, because it was found to wear well; but with the development of high speed, high pressure engines, carrying heavier burdens, the friction increased at such a rate, necessitating frequent renewals of expensive forgings, that engineers were compelled to modify the hardness of the bearing alloy.

Nowadays it is the rule to have the bearing made of softer material than the journal, and the convenience and economy of repairs are found to be considerable. The same principle is applied in various ways in ordinary brass foundry practice, as for example, in casting the plug for a stop cock, or seat for a stop valve, a softer alloy is used than for the cock or valve, so that a longer life is insured, and after the wear of the plug has reached the limit, a new one may be fitted to the same barrel.

When phosphor bronze was first introduced as a practical alloy some 30 years ago, Kunzel recommended an alloy which has been highly successful for bearings, and the frictional parts of machines. The alloy referred to consisted of copper, 66½ to 91½ per cent; lead, 4 to 15 per cent; tin, 4 to 15 per cent; phosphorus, ½ to 3 per cent. It is worthy of note that the mean of these figures gives an alloy with proportions almost equivalent to the locomotive bearing bronzes in use on many of the largest railway systems at the present time.

Several years ago the Pennsylvania railroad made an exhaustive series of tests with various combinations of copper, tin, and lead, in order to determine the best composition which would be suitable for its service, and the conclusions drawn from the experiments were as follows:

A simple alloy of copper and tin showed 50 per cent more wear than phosphor bronze.

The phosphorus plays no part in preventing wear excepting by producing sound castings.

Wear increases with the content of lead.

Wear decreases with the diminution of tin.

Alloys containing more than 15 per cent lead, or less than 8 per cent tin, could not be produced because of segregation, but it was believed that if the lead could be still further increased and the tin diminished and still have the resultant alloy homogeneous, a better metal would result. A very common complaint against hard gun-metal as a bearing alloy is "tin spots," that is, hard patches due to a localized excess of tin in the alloy. From the examination of the microstructure of bearing metals, Prof. Saveur has come to the conclusion that alloys of copper, tin, and lead, are superior to the hard copper and tin mixtures for friction-reducing qualities and durability.

TABLE XI

Bearing Metal Mixtures

Suited for	Copper, per cent	Tin, per cent	Lead, per cent	Phosphorus copper, per cent	Arsenic, per cent	Manganese copper, per cent
Bearings	85	11	..	4	..	..
Bearings	80	8	8	4	..	..
Bearings	80	10	..	..	..	10
Eccentrics	74	8	8	..	..	10
Pinions	16	2	..	1	..	..
Steam cocks	100	12	12	..	..	..
Bushes	75	11	7	7	..	..
Slide valves	70	10	3	7	..	10
Bearings	80	10	7	3	0.80	..

A high place among bearing metals has been awarded an alloy containing approximately, copper, 77 per cent, tin, 11 per cent, and lead, 12 per cent. Arsenic bronze, that is, ordinary copper and tin bronze containing about 1 per cent arsenic, has also proved superior to gun metal for bearings. The presence of zinc in bearing bronzes is undesirable; it increases the coefficient of friction and produces a fibrous condition of the alloy which necessitates careful and regular lubrication.

A notable bearing metal containing copper, 65 to 75 per cent; lead, 10 to 30 per cent; tin, 2 to 8 per cent, is sold under the name of Plastic Bronze. The alloy of copper, 65 per cent; tin, 5 per cent; lead, 30 per cent, has a compression strength of 15,000 pounds per square inch and is used for the driving brasses of locomotives. According to G. H. Clamer, the addition of nickel causes the alloy to set rapidly and acts to hold up the lead.

In Table XI is given a list of some favorite bearing metal mixtures, compiled from original sources.

While these alloys still occupy a prominent place in brass foundry practice, the white anti-friction alloys have in great measure superseded them. To Isaac Babbitt, the inventor of the process of "babbitting" and of Babbitt's metal, belongs the honor of being the first to make practical demonstration of the utility of soft white metal alloys for reducing the friction of bearings and machine parts moving in contact.

Too much stress cannot be laid upon the fact that the patent for the "Babbitt bearing" preceded the patent for Babbitt's metal, as it was a greater innovation in the engineering practice of the time than the mere compounding of an alloy specially suited for bearings. A new principle in machine design, the interspacing of the bearing surface, was introduced, and it involved considerable inquiry into the laws of friction. Friction is a factor which has to be reckoned with in mechanics; it is a great dissipator of energy, and by it heat is produced.

Friction has been defined as "that force which tends to stop a moving body." The laws of friction as deduced from the experiments of Coulomb, Rennie, and others, present a complete and surprising contrast with regard to solids and liquids. With the former, friction is (a) proportional to pressure, (b) independent of area of contact, and (c) not greatly affected by the velocity of rubbing, while the reverse holds good with the latter. The friction of plane surfaces gliding over each other, which is the subject immediately under our observation, is influenced by the nature of the bodies in contact, and varies in the ratio of the weight and pressure of the rubbing parts, and the time and velocity of their motions. The ratio obtained by dividing the entire force of friction by the normal pressure is called the coefficient of friction. Or to put it another way, the coefficient of friction is the ratio of the force of friction to the force pressing the bodies together. The following are the average values with smooth surfaces on the several materials metioned:

Coefficients of Friction

Metals on metals, dry	0.15 to 0.2
Metals on metals, lubricated	0.03 to 0.08
Metals on wood, dry	0.3 to 0.6
Leather on metals, dry	0.5
Wood on wood, dry	0.3 to 0.6

Since the introduction of babbitt metals, the coefficients of friction have been considerably lessened. Numerous tests with various first-class babbitt metals have shown the following averages: Coefficient of friction 0.012, with load of 500 pounds per square inch and velocity of rubbing surface 500 feet per minute; compression on 1 cubic inch with loads of from 5 to 10 tons per square inch, 0.010 to 0.070; tensile strength about 8,000 pounds per square inch; melting point 450 degrees Fahr.

The white anti-friction metals are now more numerous than the brasses and bronzes which they were originally intended to displace. "Babbitt metal" has about lost its individuality and the term has been applied to many concoctions which Babbitt would have disowned. Things have come to such a pass lately that manufacturers have been compelled to classify alloys containing over 80 per cent tin as *Genuine Babbitt Metal.*

A brief summary of the qualities sought after in alloys intended for anti-friction purposes may help us to understand some of the causes of failure with haphazard methods of mixing or buying. The term anti-friction metal is based on the fact that certain metals offer little frictional resistance under a heavy load when in contact with other metals. But it must not be thought that high-pressure capacity is the most important requirement in bearing metals. The speed, lubrication, condition of running, and other factors are sometimes of greater moment than the mere burden which the bearing may have to carry. However, the characteristics of the white anti-friction metals, as a class, may be summed up thus:

They produce less friction and require less lubrication than any other class of metals or alloys.

Within certain limits they sustain great pressure without undue abrasion or compression. They are generally sufficiently soft to adapt themselves to the bearing surface, and they do not readily cut the journal.

They are comparatively indifferent to the action of sea water, acids, etc.

They have low melting points and are easily manipulated.

They have small contraction, and they adhere well to other metals. In addition to the qualities necessary for ordinary anti-friction metal, submerged bearings require to be somewhat neutral to galvanic action and must offer a high resistance to electricity.

With all these questions under consideration it is little wonder that there is great diversity of opinion among engineers regarding the most desirable elements and proportions for anti-friction metals. The white anti-friction metals may be divided, for convenience in distinguishing them, into four classes:

Genuine babbitt metals, or those alloys having over 80 per cent tin in their composition.

Plastic metals, or those best adapted for pasting purposes.

Anti-friction metals, or those having lead as a base.

White bronzes, so-called, or those suitable for sand castings, generally having zinc for the base.

This is by no means the accepted classification of these alloys, but they are growing so numerous that some such classification will soon be necessary.

Babbitt's metal.—Babbitt's metal, according to the formula for which the patent was granted, was a ternary alloy, consisting of copper, 3.7 per cent, antimony, 7.4 per cent, and tin 88.9 per cent. It was made by the good old-fashioned method of melting a portion of the components separately, producing what is known as "hardening," or "temper," melting the quantity of tin required to complete the alloy and adding in the necessary proportion of hardening.

The best alloys are still made in this manner, irrespective of the metal used as a base. The phenomenal success of babbitt metal as a friction-reducing substance did much to promote the efficiency of modern machinery, and it was to a great extent instrumental in developing speed and economy of power. But no alloy made for a special purpose could be expected to possess the same properties under altered conditions, hence the call for modifications of Babbitt's formula to meet the views of progressive engineers and to keep pace with the economies of modern engineering. Much study has been given to the metals in their relation to friction.

Some years ago Prof. Goodman made a series of investigations to determine the effect on the frictional resistance of minute additions of other metals, to a lead, tin and antimony alloy. He discovered that by the addition of from 0.03 to 0.25 per cent of bismuth, the alloy acquired an almost incredible increase of anti-frictional qualities, while a similar admixture of aluminum had the reverse effect. Some of the anti-friction metals, though supposed to be the same, gave frictional results differing by as much as 100 per cent. Analyses of the samples showed that the principal constituents were present in about the same proportions, but that there were differences in the amount of impurities present. Very minute quantities of some elements showed a marked effect on the friction—some increasing and others diminishing it—-and further investigation proved that those elements of low atomic volume, $\left(\frac{\text{Atomic Weight}}{\text{Specific Gravity}}\right)$ increased the frictional resistance, while those of high atomic volume decreased it, provided that they were present in small and definite proportions.

The addition of 0.1 per cent of aluminum, which has an atomic volume of 10.6, produced 30 per cent increase in the frictional resistance, while the addition of bismuth, which has an atomic volume of 21.1, immediately reduced the friction. It would seem, therefore, that some elements, as bismuth, arsenic or phosphorus, have a beneficial influence on anti-friction metals, while other elements, as aluminum, iron or nickel, have a contrary effect. Table XII enables us to contrast the properties of the metals in relation to friction.

Assuming that the viscosity of liquids is conducive to friction, and low specific heat combined with fusibility and hardness are desirable qualities in lining metals, we have sufficient reason for considering that those metals which do not run freely, as aluminum, copper, zinc, and those which assume a pasty condition near to the point of solidification, as aluminum and iron, are less suited for reducing friction than metals possessing good flowing power, along with these other qualities. The benefits of arsenic in lead, phosphorus in bronze, bismuth in solders, and mercury in bismuth alloys or fusible metals, in increasing fluidity, and fusibility, are already well known, but the benefits derived by combining metals of high atomic volume and low specific heat and conductivity are not generally understood.

TABLE XII

PROPERTIES OF METALS IN RELATION TO FRICTION

Heat conductivity	Hardness	Viscosity	Fusibility	Specific heat	Atomic volume
Copper	Antimony	Aluminum	Tin	Aluminum	Bismuth
Tin	Bismuth	Copper	Bismuth	Iron	Antimony
Iron	Iron	Antimony	Lead	Zinc	Lead
Lead	Zinc	Iron	Zinc	Copper	Tin
Bismuth	Copper	Zinc	Antimony	Tin	Aluminum
	Tin	Lead	Aluminum	Lead	Zinc
	Lead	Tin	Copper		Iron
			Iron		Copper

Taking the metals as arranged in the above table, a glance may show that if heat conductivity only had to be considered in selecting metal for anti-friction purposes, bismuth, the lowest conductor of the series, would best meet the requirements; if hardness was the indispensable condition, then antimony would be the ideal metal, and so on through Table XII, reading the columns from left to right.

The physical structure of metals and their chemical affinities combine to regulate the production of alloys conducive to the lowering of friction. Bismuth, we have seen, possesses many excellent qualities of this kind, but it lacks cohesion, and is therefore unsuitable as a base for a bearing alloy. Lead makes a good second to bismuth in three of the most desirable properties, heat conductivity, fusibility and atomic volume, and but for its known softness, which causes it to spread and flow under pressure, it would, by itself, make a first-class anti-friction metal. The anti-friction alloys having lead for their base are daily increasing. They are hardened and have their melting points regulated to suit various conditions, by admixtures of copper, antimony, tin, bismuth or arsenic. In the words of an advertisement, "they have a graphite-like surface which is partially self-lubricating."

Prof. A. Humboldt Sexton declared at a public lecture in the Technical College, Glasgow, that the extraordinary success of the well-known "Magnolia Metal," was due chiefly to the combination in suitable proportions of the metals—lead, antimony and bismuth.

Impurities in bearing mixtures.—We have already seen that a very slight amount of impurity in the alloy used for bearings may increase the coefficient of friction and cause untold mischief. As all the commercial metals contain more or less impurities, it becomes manufacturers to guard against those elements which are known to increase friction, as aluminum, iron, nickel, and to be careful that the method of making up the alloys does not add to the content of impurities. Some firms announce that their metals "can be melted in an iron pot and they do not deteriorate by remelting." Such a statement is either an evidence that zinc or phosphorus are not contained in the alloy (if they were they would attack the iron), or else it contains one of those ingenious phrases put out by advertising experts to sell the goods.

Crucible melting is acknowledged to give the best results, and if large quantities are required, a furnace with a silicious lining is preferable. Enough has been said to show the need for considering the properties of the metals and the peculiar conditions which go to make good anti-friction alloys.

Compounding anti-friction alloys.—The salient points to be observed in compounding anti-friction alloys are condensed as follows:

Anti-friction alloys are better and more economically mixed by the "bath" system, or by means of "hardening," than by the direct fusion of the components.

They should not be heated to redness—the proper heat may be judged by inserting a pine stick; it should smoke or singe, but not burn.

If the alloys are overheated, antimony and zinc are decreased by volatilization, and a greater amount of separation of other constituents occurs in the process of solidification.

For all around excellence, genuine babbitt metals are to be commended.

For a cheap metal to give good wear, alloys with zinc in the base give satisfaction, *if properly lubricated.*

For a metal requiring little attention at high speeds, alloys having lead in the base are the most suitable.

Plastic metals should contain little antimony, as that metal forms a grit on the bolt or pasting-iron, and prevents the flow of the alloy.

Aluminum and nickel are altogether unsuitable elements in anti-friction alloys.

Beware of alloys whose virtues are advertised in the negative form.

A metal with a low coefficient of friction runs cooler and requires less lubrication than one with a higher coefficient.

The temperature of fusion is lowered by about one-seventh in ordinary practice; this is due to the pressure.

Traces of impurities have not the far-reaching effects in brass alloys that they have in gun metals or anti-friction alloys.

Arsenic tends to crystallize other metals; it also promotes the union of other metals that would otherwise be difficult to mix.

Phosphorus prevents blistering, promotes fluidity and increases hardness.

Manganese is recommended for hydraulic machinery, or where chemical solutions give rise to corrosion with the ordinary alloys.

Powdered sal-ammoniac is the best flux for babbitt metals.

Sawdust is a good protection for the alloys in the molten state.

A metal, not an alloy, which takes a high polish is better for linings than one which takes a dull polish. This would indicate the need for a close-grained metal.

Anti-friction alloys are manufactured in three grades or degrees of hardness, to suit the varying load, speed and duty of machines. In testing the comparative values of alloys as anti-friction metals, these things should be fairly considered. Oftentimes destructive tests are made in laboratories, with the object of fusing the metals by abnormal pressures and conditions. The conclusion to be drawn is that the metal which sticks or fuses first is the worse anti-friction substance. This is hardly a fair test, as it neglects to consider the duty for which the metal is designed. The only practical test for such metals is the coefficient of friction in actual working conditions.

Dual alloys.—The early attempts to produce anti-friction metals were mostly dual alloys, 10 per cent compounds of copper in tin, copper in zinc, antimony in tin, or antimony in lead; but the limitations of these alloys were far from satisfying the general requirements. Dual alloys, therefore, are an unimportant class, entirely out of favor, except in one or two special cases, as lead and antimony, called antimonial lead, for submerged light bearings or chemical plant, or tin and antimony, for gas plant machinery. An example of the latter used by a large firm of meter manufacturers is composed of tin, 75 per cent, antimony, 25 per cent. For light machinery running at ordinary speeds an alloy of lead and arsenic, known as "shot" metal, makes a splendid anti-friction metal. Table XIII gives a selection of the best alloys derived by analysis or from the formulas of the makers. These alloys are all of proven excellence, and, although they have not been set down in the order of their merit, they have been selected from the very best authorities and practice in the engineering world.

TABLE XIII

Some of the Best Babbitt Alloys

Copper, per cent	Tin, per cent	Antimony, per cent	Lead, per cent	Zinc, per cent	Bismuth, per cent	Name.
3.8	78.56	11.8	6	..	..	Navy bronze No. 1
8	83	9	..	..	..	Admiralty special
1.80	64.70	..	1	33.35	..	Parsons
4	35	17	44	..	..	Navy bronze No. 4
7	80	2	10	..	1	Plastic metal
...	18	2.5	4.5	75	..	White brass No. 1
3.64	22.14	..	..	74.22	..	White brass No. 2
...	42	12	46	..	..	Lining metal
2.50	..	16.43	80.24	..	0.76	Universal bearing metal
...	48	4	..	48	..	Marine bronze
7.5	84	7.5	..	..	1	Motor bronze
8	75	17	..	..	..	Locomotive bearings

"*Babbitt, the man and the metal.*—Babbitt, Isaac, American inventor, born Taunton, Mass., July 26, 1799; died May 26, 1862. Served an apprenticeship to the goldsmiths' trade and early became interested in the production of alloys. In 1824 he manufactured the first britannia ware in the United States. In 1839 he discovered the well known anti-friction metal, for which the

Massachusetts Charitable Mechanics Association awarded him a gold medal and congress subsequently voted him a pension of $20,000."

The insertion of this excerpt from the *Encyclopaedia Americana* may serve to describe the man who introduced that most popular alloy of the 19th century—babbitt metal. Many people have hazy notions of Babbitt, babbitt metal and babbitting.

Babbitting, or the lining or interspacing of bearings with anti-friction metal has done more to increase the speed and economy of modern machinery than any other single process or practice in engineering.

Remember, Babbitt manufactured britannia ware and britannia metal is an alloy of tin hardened by antimony and copper Babbitt's metal, therefore, was purely and *simply a britannia metal,* and when he had finished with the making of it, it consisted of tin 88.9 per cent, antimony 7.4 per cent and copper 3.7 per cent. The figures give us no information about the method of combining the metals and that is the most important thing in the production of alloys intended to undergo mechanical treatment. The improvements in the modern bronzes are as much due to correct methods of combining the metals as to the introduction of new elements. It is recognized nowadays, that the mere melting and mixing of metals together, regardless of their chemical qualities, does not conduce to the highest excellence in the combination. The direct melting of the metals to produce an alloy of more than two metals is a crude process, wrong in principle and generally unsatisfactory in the final result. The use of "hardening," "remelting," "temper" and "fluxes" must be understood in order to get the best results from babbitt metal. Even the order in which the metals are melted and blended is of some importance. The proper course is always to make a "hardening" for alloys of metals showing disparity in fusibility and specific gravity. Babbitt's "hardening" was made by melting copper 4, then adding gradually tin 12, antimony 8, and finally a further addition of tin 12. To make the "lining" metal 72 parts of tin was melted and the 36 parts of "hardening" dissolved therein, so that the alloy was made at a low temperature—practically at the heat of melted tin.

Overheating anti-friction metals.—Overheating is a fruitful cause of dissatisfaction with the wearing and working qualities of anti-friction metals. The effect of high temperatures on metals of low fusibility is always harmful, more especially if the metals have a tendency to crystallize. In cooling, the refractory combinations (copper, antimony, tin) set first, leaving the more fusible combinations (tin, antimony, copper) to solidify on the surface. That is why in the directions for using genuine babbitt metals we are told to cast the working face of the bearing downwards if possible, and to avoid high temperatures and slow cooling. The latter conditions produce bigger crystals and a greater separation of the constituents in the alloy weakening its cohesive force and increasing the coefficient of friction.

The properties which make babbitt metal so valuable are its power of accommodating itself to a hard unyielding surface, its capacity for taking a polish, its power of resisting certain chemical influences, and its low melting point. Genuine babbitt metal will not cut, scratch nor heat the journal, and after being in use for some time, the bearing takes a glittering appearance on the surface. But all that glitters is not babbitt! The variations in the genuine babbitt metal are limited, but the commercial grades sold for babbitt metal are endless and the prices sometimes prove that tin is regarded as a luxury.

During the years of my apprenticeship Babbitt's patent metal was the only thing available for lining bearings, etc., but in 25 years many changes are possible. It was found that babbitt alloy was greatly improved as a self-lubricating metal for fast running light machines, when a portion of the tin was replaced by lead. Further experience brought out the truth that properly hardened lead was equal to hardened tin as a metal for anti-friction purposes. 'Twas then the flood arrived!

For some years it rained anti-friction metals. They were registered under all sorts of fancy titles. Beginning at *Zero,* they worked right through the *Glacier-cum-Glyco* period into the heart of Greek mythology. By comparisons the staying powers of *Atlas,* the strength of *Hercules* and the defiance of *Ajax* were set at nought. The *Bull* and the *Bear* were driven *Tandem* on the market, while the *Stone* and *Rock Bronzes* understudied the

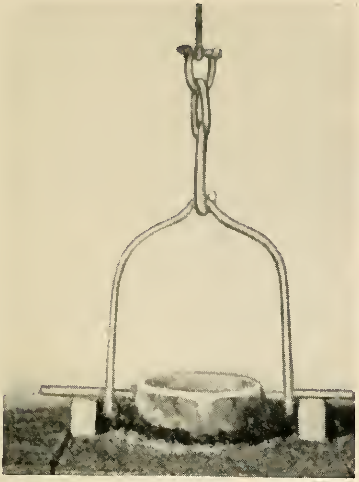

Fig. 11—Melting babbitt metal in a 500-pound crucible in a pit furnace

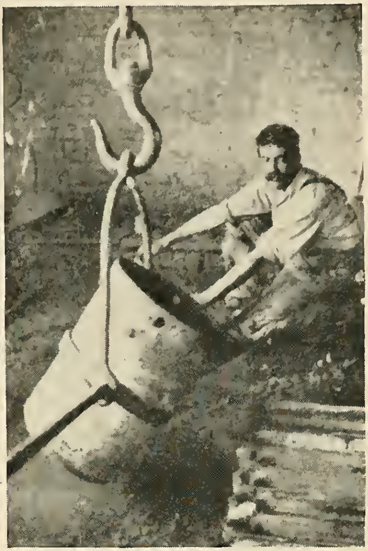

Fig. 12—Method of handling the 500-pound crucible when pouring the metal

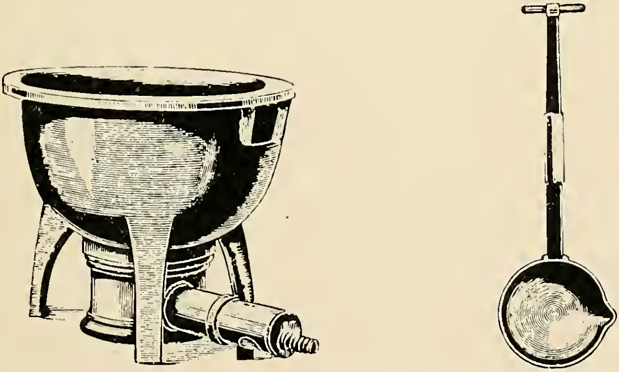

Fig. 13—Cast iron gas furnace and ladle for babbitt metal

Parsons. At the sign of the *White Ant* the *Navy* casts *Anchor* and upholds the *Crown.* There are too many of them; we shall soon want a standardizing bureau for the anti-friction alloys,—registered and unregistered, equal to babbit, better than babbitt and—Babbitt.

How to make babbitt metal.—Now, if you should happen to want the best babbitt or anti-friction metal that can be made, make it yourself thus:

Select the purest metals that can be had and the most suitable formula for the duty of the alloy; make a preliminary mix of the refractories in a plumbago crucible and pour it out for "hardening." Melt the metal which form the basis of the alloy, (it may be tin, lead, or zinc,) and dissolve the hardening therein, at a gentle heat, using sawdust, tallow, or powdered sal-ammoniac for a flux. For making a large quantity in the ordinary brass furnace make a cast iron crucible two inches smaller than the diameter of the furnace; lower it into the furnace and lute round as shown in Fig. 11. Fig. 12 shows how conveniently such a pot may be handled. The capacity of this one is 500 pounds. A more uniform grain may be had from a good sized melt than is possible with a small lot. One word of caution is needed here. Zinc should not be melted in an iron pot, but if melted in a plumbago crucible it may be poured and mixed with the other components of the alloy already melted in the pot.

Another very convenient furnace for remelting all kinds of babbitt and anti-friction alloys is shown in Fig. 13. This style of furnace is not recommended for *making* the alloys unless where "hardening," already prepared by melting the refractory metals together, is used; but it is handy for lining metals which are poured with a hand ladle, and it may be moved about to any place where there is a gas union.

The utility of babbitt metal is not to be gaged by the number of cents it costs per pound. A cheap babbitt, lead or zinc base, well made, may give better service than a costly mixture which has been carelessly blended. Besides the commercial grading of metals by number or title is like the private marks of retail merchants, unintelligible to the outsider. Generally the grades are for (1) light loads and high speeds, (2) medium loads and moderate speeds, (3) heavy loads and slow or moderate speeds, and (4) heavy loads and high speeds. Such grading is reasonable, for the hardness of the alloys increases with the numbers, and price does not count. The time for selling alloys by analysis is not yet, but "Come it will for a' that."

To sum up, babbitt metal is essentially a tin alloy, but modern engineering practice and commercial usage favors the continuance of the name to all metals capable of the same duty as babbitt. Hence we get three series of babbitt or anti-friction metals: (1) the tin series, (2) the lead series, (3) the zinc series. Tin is the most polishable of the soft metals, and it alloys readily with any of the useful metals employed for minimizing the friction of machinery; it has been made the basis of the best anti-friction alloys. Lead is undoubtedly the best anti-friction medium among metals, but it lacks a great deal of stiffness to stand up to the work. Copper is the ideal bond for zinc alloys, and zinc is the most expansible and durable of metals. Zinc babbitts cast well, wear well and fit snugly to the bearing.

TABLE XIV

Special Babbitt Mixtures

For lining	Tin, per cent	Lead, per cent	Zinc, per cent	Antimony, per cent	Copper, per cent	Bismuth, per cent
Dynamos, high speed	88	..	..	8	3.5	0.5
Marine engines	77	17	..	3	3	..
Eccentrics	5	78	..	15	2	0.25
Submerged bearings	40	48	..	10	2	..
Main bearings	34	44	..	16	6	..
Slides, thrusts	65	..	30	2.5	2.5	..
Railway trucks	42	..	56	..	2	..
Axle boxes by analysis	74.22	13.50	1.80	6.55	3.60	..
Anti-acid metal by analysis	78.84	14.75	..	trace	3.70	..
Plastic metal	80	10	..	1	8	1
Genuine babbitt (hard)	80	..	..	10	10	..
Genuine babbitt, No. 2	83	..	..	9	8	..
Universal bearing metal	6	78	..	16	..	0.25
Anti-friction castings	24	..	80	..	4	..

Owing to its highly crystalline structure, antimony, the principal hardening element, should not exceed 20 per cent, as it is apt to separate and rub out of the alloy. Seventeen per cent has been fixed as the limit by an eminent authority.

There are critical points in many alloys of the common metals. Lead and tin may be united in any proportions, but the hardest alloy of the two metals is obtained when they are present in the ratio of 4 and 6 respectively.

The mutual relations of the metals determine the mechanical properties of the alloys. Zinc and antimony are too much alike to be used simultaneously and tin alloys, without copper, are apt to spread under heavy loads. Due to its poor affinity for lead and tin and its low atomic volume, aluminum is not a suitable metal for anti-friction alloys. Bismuth, on the contrary, is a decided advantage up to about 1.5 per cent. This metal has been freely used in the production of some modern alloys, notably those with low fusibility, low contraction and high atomic volume. In Table XIV are given some special mixtures which have given complete satisfaction for the duty stated.

Lastly, we have the mixtures of a manufacturer representing four grades as given in Table XV.

In each case the metals represented by the figures, 7, 17 and 6 constitute the "hardening." These are what are termed copper hardened alloys,—the copper content being over 5 per cent. This series is worthy the attention of all who are seeking for cheap, serviceable anti-friction metals. The composition of a special manganese babbitt follows: Tin 80 per cent, lead 10 per cent, antimony 7 per cent and manganese-copper 3 per cent.

TABLE XV

Grades	No. 1 per cent	No. 2 Per cent	No. 3 per cent	No. 4 per cent
Tin	77	77	17	..
Zinc	..	17	77	77
Lead	17	7	7	17
Antimony	7	..	..	6
Copper	6	6	6	7

An anti-friction paste, recommended for fans, etc., running at high speed, follows: Tallow, 6 parts; plaster of paris, 3 parts; beeswax, 3 parts; blue butter, 1 part; plumbago, 1 part. Melt together and allow to cool before using.

IX

FOUNDRY MIXTURES

IN striking contrast to the simplicity and exactness of the formulas specified for standard alloys, the mixtures used in brass foundries generally are variable. The ordinary foundry metals are therefore of unequal properties, and the methods employed in their manufacture are sometimes of doubtful value. Commercialism seems to dominate the brass industry to the prejudice of its products. There is more fictitious valuation permitted with brass founders' alloys than would be tolerated in any other department of the foundry business. Brass has become a name signifying a metal yellow in color. Gun metal is a convenient term for alloys of more coppery appearance, and in these days when things are being sold, which, according to the advertisements "operate to increase the chemical affinity between the different elements of a mixture, and tend to determine the copper or higher colored elements to the surface," any old metal may be converted into respectable, colorable gun metal. All alloys are the outcome of experiment and research, and as improvements in the manufacture of alloys have had to keep pace with other advances in the metal industries, many processes, having no bearing on the intrinsic merits of the metals, have been adopted in general foundry practice. For example, to avoid the loss due to remelting, many excellent gun metals are made by introducing into molten copper, old metals of known proportions, as yellow brass, bell metal, plumbers' solder, etc.

The art of mixing old metals and producing castings of good uniform grades requires a deal of skill, experience and good judgment. So many things may be overlooked in passing a heap of scrap. Some pieces may appear clean and even in the grain, yet the effect of a very small percentage of either antimony, or aluminum in them would be to ruin the whole mixture for many kinds of castings. Every firm has its own methods of manufacture and its own stock-in-trade of mixtures suited for particular classes of work. Every foundry foreman, too, has his favorite mixtures and a note book which he prizes more than a whole technical library.

TABLE XVI

Metal	"Ash" Metal, per cent	M. Ingots, Per cent	H. G. M. railway, axle bars, per cent
Copper	71.60	75.55	82.75
Tin	5.00	1.45	13.04
Zinc	5.42	20.80	3.81
Lead	17.55	2.00	.....
Antimony	0.40	.....	0.35
Total	99.97	99.80	99.95

The need for this note book will be most apparent to those who best understand the delicate and complex nature of certain alloys and the alternative methods of making them. The blending of metals is as much an art as the treating of foods or fabrics, and the recipes in the first mentioned business are equally important. The metal-mixer who is called upon to produce alloys to specification, from old metals, must work up a system of averages. For the purposes of the mixtures in Table XVI, yellow brass was reckoned to average, copper two-thirds, zinc one-third,

TABLE XVII

STANDARD ALLOYS FROM MIXED METALS*

Copper	Tin	Lead	Yellow brass	Bell metal	"H. G. M."	Representing standard			Castings for
53	..	..	18	28	...	Copper 87	Tin 8	Zinc 5	Merchant ship
20	..	..	..	..	100	Copper 88	Tin 10	Zinc 2	H. M. S. "Dido"
84	11	..	4	..	...	Copper 88	Tin 12		Fire Brigade Hydrant, Edinburgh
41	..	...	20	32	...	Copper 14	Tin 1	Zinc 1	Trinity Marine Board, London
1	..	1	..	..	10	Copper 81	Tin 10	Lead 9	Glasgow Corporation Sewage Plant

*All of these metals stood the physical tests required from the specified alloys, notwithstanding deviations as great as 1.7 per cent from the quantities stated in the specifications.

bell metal to contain 18 to 20 per cent tin, and the analyses of mixed metals in stock in the foundry where these alloys were made as given in Table XVI, were sufficient guide to attain satisfactory results as shown in Table XVII.

Numerous examples might be given of ordinary brass founders' alloys being made from a collection of old metals but a few will suffice to show how much may be done by studying the characteristics and contents of the scrap heap.

Brazing metal.—Brazing metal may easily be made by adding to melted copper from 1 to 3 times its bulk of brass tubes or sheathing. A common practice in making cheap gun metals is to melt a quantity of mixed brass scrap and add an equal quantity of standard gun metal, (Copper 9, tin 1). An excellent anti-friction alloy for high speed, low pressure machines results from the following mixture, lead shot, 100 parts, antimony 6 to 10 parts. The arsenic in lead shot has a great influence on the anti-friction properties of lead-antimony alloys.

TABLE XVIII

SPECIMEN FOUNDRY MIXTURES CONTAINING SCRAP OR OLD METALS

Copper	Tin	Zinc	Lead	Yellow brass	"Ash metal"	"H. G. M."	"M" ingots	Cock metal	Name
20	...	..	2½	15	....	...	..	..	Cock Metal
28	1	..	...	10	....	...	..	7	Red Metal
16	1	..	2	..	....	...	..	4	Red Metal
16	2	..	1	6	....	...	..	..	Pan Metal
16	1	..	3	6	....	...	..	..	Pan Metal
64	8	..	...	6	....	...	..	..	Screw Metal
16	...	..	...	8	1	...	..	..	Screw Metal
16	1½	..	...	2	....	...	..	..	Bolt Metal
93	5	2	...	..	....	...	..	10	Steam Metal
20	2	..	1	10	....	...	..	..	Steam Metal
16	1½	..	1	4	....	...	..	..	Steam Metal
40	...	..	...	30	....	30	..	..	Gun Metal
16	2	..	...	2	....	...	..	..	Gun Metal
64	15	..	...	1	....	...	..	..	Bell Metal
64	4	..	1	8	....	...	..	..	Art Metal
32	3½	..	2	..	....	...	32	..	Bush Metal
32	5	..	1	5	....	...	..	..	Bush Metal
20	3	..	...	14	....	...	..	..	Bush Metal
50	...	..	...	..	10 to 30	100	..	..	Bush Metal
16	1	..	...	..	1	...	10	..	Bush Metal
2	...	..	1	..	4	18	6	4	Bush Metal

Another alloy in which lead shot figures is known as "Ajax" bronze--copper 100 parts, tin 12½ parts, arsenic lead 12½ parts.

This is an excellent bearing metal; it is also well suited for cocks and fittings for chemical plants.

The most reliable anti-acid metal is made from copper 3 parts, antimonial-lead 1 part. Good steam metal may be made by simply adding 15 per cent plumbers' fine solder to molten brazing metal. This is a convenient way to use up old flanges. Other examples of mixed metals being used for practical combinations will be found in Table XVIII. The qualities are given in round figures, and may be read as pounds, or as parts in ratios suited to the capacity of the crucible or the work to be cast. It is customary in brass foundries to have the composition or alloying metals, fixed in relation to the pound of copper, therefore most of the figures are either multiples or fractions of sixteen, the number of ounces in the pound avoirdupois.

Many brass founders run away with the notion that the mixture is everything and forget that the melting practice is the most important part in the mixing of metals. Some pride themselves on possessing certain recipes which they imagine give them advantages over their competitors. Experience is the best guide, and careful attention to details the best recipe, for the blending of metals into alloys. Foundry alloys are mostly regulated by the metals available and the prices obtainable for castings. The relative weights of the metals entering into an alloy are of some importance in the final value of the castings.

The addition of aluminum in an alloy is sometimes an economy, just as the addition of lead—the cheapest adulterant, is frequently made a means of gain. The high or low specific gravity of the alloy makes a difference in the price or the profit.

Typical brass founders' alloys.—The general public has an idea that the brass trade is one, at least, in which there can only be a limited amount of trickery. In some quarters, anything having the color of brass will suit, even if it is mainly zinc; and in others, a metal having the color and fracture of gun metal is as good as the best. Yellow brass and gun metal are probably the two most prominent alloys on the brass founders' list, but they have ceased to be the typical metals they were in the good old days before brass founders knew more than one way of making them, unless in shops working to standard formulae and requirements, or where specifications and tests are part of the contract. I do not mean to infer by this that the brass founder is degenerating, or that he has lost his cunning in mixing the alloys, but rather that the exigencies of trade, price-cutting and competition, have left him no other possible way out than by a skillful manipulation of the metals within the limits of his customers' specifications. The ideal has almost been attained in iron founding; cast iron will in all likelihood, soon be bought, mixed, and sold, *universally,* by desirable chemical standards, and the mechanical tests required will be obtained by methods of melting and casting. Surely if it is a *desideratum* to seek for exact proportions of the elements in various grades of cast iron, it is none the less necessary in different qualities of brass. It used to be that the quantities of zinc or tin periodically consumed were a sufficient index of the character of the work done in a brass foundry. Nowadays, when the brass refiner is a power in the land, and the habit of buying mixed metals, ingot, and scrap, has grown to be recognized as a necessary evil, the line cannot be drawn so easily which separates brass and gun metal, or the legitimate use of the cheaper metals in the manufacture of brass founders' alloys.

TABLE XIX

SPECIMEN AIR FURNACE CHARGES, CONTAINING SCRAP AND OLD METALS

Castings	Copper	"H. G. M."	"M" Ingots	"Ash Metal"	Lead	Pan metal	Remarks
Pumps	10	50	..	..	..	..	Centrifugal pumps
Pumps	4	10	8	..	..	..	Ciculating pumps
Liners	10	25	16	2	..	..	Fluid, close grained
Liners	5	10	..	10	..	5	
Propellers	6	24	2	..	..	..	30 pounds phosphor-copper added
Tube plates	16	4	6	..	..	4	Good red metal
Brasses	4	10	..	3	..	..	
Stern tubes	16	8	16	..	2	..	
Brasses	1	10	..	..	1	..	Sugar mill bearings
Steam Pipes	3	3	3	9	..	..	Mixed borings, 140 pounds
Sluice Valves	22	..	4	22	..	..	Fluxed with 18 pounds old bottles

Perhaps we cannot better illustrate this point than by giving the reply of a foreman brass molder, who, when asked to purchase a recent book dealing with brass founders' alloys, said:

"What do I want with a book of mixtures, when all I get to mix is a bar o' lead and a barrel o' sojer's buttons?" Fortunately, this is an extreme case, and the resources of the average brass founder are not confined to such puerile commodities. Nevertheless there is a suggestiveness about that "bar o' lead," which will appeal to the engineer or trader handling either marine or jobbing brass castings. It is due to the refiner to say that he has in great measure educated brass founders and opened their eyes to new possibilities in the matter of serviceable alloys, high-tension alloys and alloys containing the base metal. The staple product of the brass refiner in Great Britain is known to the trade as *Ash metal.* This is a low grade brass containing all sort of impurities; it is reduced from skimmings, furnace ashes, buffings, chips and sweepings, and when a sufficient quantity for a heat has been washed it is smelted and tested to see how much lead or zinc it will carry before being run into ingots for the market. Ash metal has really no claim to the name of brass unless for its color, and then it sometimes might with equal jus-

TABLE XX

SPECIMEN FOUNDRY ALLOYS, FROM NEW METALS, IN POUNDS

Copper	Tin	Zinc	Lead	Aluminum	Antimony	Nickel	Iron	Phosphor-Cop.	Used for
16	1	1	1	..	..	..	..	..	Cocks, valves, etc.
80	6	8	6	..	..	..	..	..	Marine brasses
16	2¾	...	¼	..	..	..	..	..	Locomotive brasses
80	10	10	....	..	..	..	..	..	Propellers
80	8	4	8	..	..	..	..	..	Mill brasses
16	1	1	2	..	..	..	..	..	Cock metal
92	4	1	2	..	..	..	..	1	Pinions
95	4	...	....	1	..	..	..	..	Hydraulic pumps
82	11	3	2	..	..	..	..	2	Bearings
88	8	...	3	..	..	..	..	1	Slide valves
88	9	3	....	..	..	..	..	..	Gun metal
17	.....	15	1	..	..	8	..	..	German silver
28	.....	12	1	..	..	9	..	..	German silver
45	.....	30	....	2	..	..	..	..	Aluminum brass
4	110	48	....	..	2	..	..	..	Babbitt metal
2	84	112	....	..	..	..	..	..	Babbitt metal
57	1	40	....	..	..	..	2	..	Delta metal
10	.....	80	....	3	..	..	..	..	White brass
80	8	4	....	..	..	..	..	..	Gun metal
4	35	...	44	..	17	..	..	..	Navy bronze
...	.....	...	....	91	1	..	..	8	Art metal
140	12	...	....	..	..	..	..	12	Phosphor bronze
55	1	40	....	..	..	1	3	..	Manganese bronze
100	12	8	....	..	..	..	..	..	Spring metal

tice be termed German silver, and no self-respecting brass founder would ever dream of using it for castings by itself. He generally mixes some other metal with it to give it body, or else he uses it as a cheap reliable adulterant in new metal. To the credit of the refiner it must be said, he makes no professions about his Ash metal other than that it is cheap. The following is an analysis of a regular Ash metal sold in Glasgow in 1900: Copper 57.08 per cent, tin 1.23 per cent, zinc 25.65 per cent, lead 14.12 per cent, antimony 0.42 per cent, iron 0.61 per cent.

Every well managed foundry has a system of collecting and using its own scrap, borings or surplus metals, for the regular grades. Most difficulty is experienced in connection with "foreign" scrap, or metals which have to be judged by appearance or by mechanical tests. Alas! appearances are oftentimes deceiving and even mechanical tests may be misleading as to the blending or alloying properties of a metal which behaves decently if taken by itself. In the examples already given, the custom of making alloys from mixed metals is exemplified, but the analyses furnished with these mixed metals made it easy to graduate the components in the finished alloy. This is the exception: the rule

TABLE XXI

CONSTITUENTS AND RANGE OF BASIS ELEMENTS IN TYPICAL BRASS FOUNDERS ALLOYS

Name of alloy.	Constituents.	Basis metal	Per cent of average content
Brass	Copper and zinc	Copper	60 to 75
Brazing metal	Copper and zinc	Copper	80 to 90
Bronze	Copper and tin	Copper	84 to 94
Bell metal	Copper and tin	Copper	78 to 84
Gun metal	Copper, tin and zinc	Copper	80 to 90
Steam metal	Copper, tin, zinc and lead	Copper	80 to 90
Cock metal	Copper, zinc and lead	Copper	75 to 90
Phosphorus bronze	Copper, tin and phosphorus	Phosphorus	0.25 to 3
Aluminum bronze	Copper and aluminum	Aluminum	2 to 10
Aluminum brass	Copper, zinc and aluminum	Aluminum	2 to 5
German silver	Copper, zinc and nickel	Nickel	15 to 25
Delta metal	Copper, zinc and iron	Iron	1 to 3
Manganese bronze	Copper, zinc, iron and manganese	Manganese	0.5 to 5
Silicon bronze	Copper, tin and silicon	Silicon	0.5 to 2.5
Hard solder	Copper and zinc	Copper	48 to 55
Soft solder	Tin and lead	Tin	50 to 75
Anti-friction metal, grade I	Tin, antimony and copper	Tin	80 to 90
Anti-friction metal, grade II	Zinc, tin and copper	Zinc	60 to 80
Anti-friction metal, grade III	Lead, antimony and copper or tin	Lead	75 to 82
Britannia metal	Tin and antimony	Antimony	8 to 10
Type metal	Lead and antimony	Antimony	10 to 20
Fusible metal	Bismuth, lead and tin	Bismuth	15 to 40

in most foundries is to take any old metal that comes along and work it in, (lavishly or sparingly, according to quality) with the metals carried in stock.

Mixtures for chandelier work.—The most modern designs for chandelier work have brass, wrought iron and copper in combination. Brass is generally the foundation of the color scheme and many plain and ornamental castings are necessary for the completion of the design. The whole of the work is lacquered when it is finished. For the most part it is left bright but sometimes the plain parts are bronzed and relieved at suitable places by burnishing. Castings for the latter are usually made from the ordinary yellow brass, two and one alloy.

For the finer ornamental work which is to finish bright and be dipped in acids to heighten the effect of ornamentation and color contrasts, only dipping metal, or fine brass alloys may be used. Such alloys range in copper from 70 to 85 per cent and zinc from 15 to 30 per cent. The higher the percentage of copper the deeper the color of the brass, and if a paler color is required than can be had with only copper and zinc in the mixture, from one to three per cent of aluminized zinc may be added to the last named quantities.

Small additions of any metals having a tendency to harden or close the grain of the alloy will give a higher polish with the burnisher. Nickel, manganese, aluminum, tin, arsenic, phosphorus, each have this effect, but with the exception of aluminum, not more than 0.5 per cent should be present in the alloy. On the other hand the presence of such impurities as lead, iron or antimony, would be fatal to a brilliant finish in the dip. The main point therefore in making a successful dipping metal is to use only the purest metals that can be had. Remelted zinc will not do for a first-class dipping mixture; it always contains the impurities mentioned. Two first-class mixtures used by Birmingham (Eng.) founders are: Copper 19 pounds, zinc 6 pounds, and copper 30 pounds, zinc, 12 pounds, tin ¼ pound.

A brass mixture for dipping can only be cheapened by increasing the proportion of zinc and a large class of decorative work is run with mixtures containing from 7 to 14 pounds of zinc to every 16 pounds of copper, that is to say, the cheaper dipping metals show from 30 to 47 per cent zinc while the finer qualities have only 16 to 28 per cent.

For variety of color scheme, a beautiful, deep-tinted, golden bronze suitable for turned parts, results from a mixture in the following proportions: Copper 90 per cent, tin 6¾ per cent, zinc 2¼ per cent, lead 1 per cent.

Pale Gold Alloy: Copper 72 per cent, zinc 27 per cent, and aluminum 1 per cent.

Dips and lacquers.—To blacken aluminum, clean the metal thoroughly with fine emery powder, wash well, and immerse in—

	Ounces
Ferrous sulphate	1
White arsenic	1
Hydrochloric acid	12
Dissolve and add—	
Water	12

When the color is deep enough dry off with fine sawdust and lacquer.

Lacquers are ordinarily of two kinds: alcohol and products of alcohol. Good alcohol lacquers consist of shellac, and gums of various sorts, to produce colored effects, and are applied by heating the brass. The lacquer most commonly used is made by dissolving 1 ounce of soluble cotton in a quart of amylacetate and thinned with mixture of amylacetate and fusel oil to the consistency desired.

To produce a brown to black color on brass, dissolve 1 pound of plastic carbonate of copper in 2 gallons of strong ammonia. Boil the brasswork in a strong solution of potash, rinse well and dip in the copper solution which should be heated to about 160 degrees Fahr. When the required tint is procured rinse and dry off in warm sawdust, then lacquer.

Bright Dipping Acid

Sulphuric acid	2 gallons
Nitric acid	1 pint
Muriatic acid	1 pint
Water	1 pint
Nitre	12 pounds

Fumeless Dipping Acid

Sulphuric acid	10 pounds
Saltpetre	2 pounds
Water	5 pounds

Pickle For Removing Sand from Brass Castings

Hydrofluoric acid	1 part
Water	10 parts

10 to 15 minutes immersion is sufficient.

Gold Lacquer

Shellac	1 ounce
Gum benzine	½ ounce
Came wood	½ ounce
(Or Turmeric 1 ounce, Saffron ½ ounce)	
Alcohol	1 pint

Digest for a week, shaking frequently, decant and filter for use.

Silver Lacquer

Bleached shellac	1 ounce
Gum Juniper	½ ounce
Spirits of wine	1 pint

Green Lacquer for Bronze

Silver lacquer	1 pint
Turmeric	4 drachms
Gamboge	1 drachm

Chemical Bronze

Vinegar	1 pint
Crocus of suppliment	¼ ounce
Blue stone	¼ ounce

Marine brass mixtures.—Shipbuilding is perhaps the most important of all the industries creating a demand for alloys. Only the best goods will answer for ocean-going steamers and some typical mixtures for (a) bearings, (b) propeller wheels and (c) other castings used about ships will be considered. In speaking of ocean steamers there is a big choice between the common tramp and the naval cruiser. A rough classification of ocean steamers would divide them into three groups viz.: Admiralty ships, mail steamers and cargo boats. As to the first, everything put into them is of the best and the alloys used by the various naval departments may be gleaned from books on standard metals as Thurston's "Materials of Engineering." Obviously the information most sought for relates to steamers carrying passengers and cargo—merchantmen.

Taking the questions in order: (a) includes all moving parts of the ship's machinery. To explain, a ship's propeller is generally keyed on to a shaft, which passes through the stern tube and hangs over the aperture between the stern and the rudder.

In some cases an outer bearing is provided on the rudder brace.

Gun metal liners are either shrunk or cast on to this tail-shaft, which revolves in the tunnel bearings, and projects through the ship into the sea. Mixtures for shaft liners, tunnel and aperture bearings and the stern brushes are given in Table *A*.

Lead figures in these mixtures because it helps to counteract the corrosive action induced by brass and iron in contact in a moist atmosphere or under water.

As a rule, the stern tube is lined with *lignum vitae* strips or babbitt lining, and the tunnel bearings are generally cast steel, babbitt lined. A cheap babbitt is best for these parts as they are continually under water. A good mixture is lead, 80 per cent, antimony, 16 per cent, tin, 4 per cent, but a better quality, suitable for almost any part of a ship's machinery, is composed of lead, 44, antimony, 12, tin, 44.

TABLE A

Copper, per cent	Tin, per cent	Zinc, per cent	Lead, per cent	Yellow Brass, per cent	
74	12	—	—	14	Liners, to shrink on shaft
60	6	—	3	30	Liners, to be cast on shaft
81	10	—	8	—	Bearings, for aperture bushes
80	6	8	6	—	For tunnel bearings
66	6	—	4	24	Glands and bushes for stern tubes
83	10	7	—	—	Piston rings, springs, etc.
64	4	—	1	8	Steam metal
8	6	—	2	44	Bushes, common castings, etc.
100	12½	—	12½	—	Bearings
71	7	—	4	18	Valves, cocks, etc.
14	1	1	—	—	Bolts, studs
84	11	—	—	4	Hydraulic connections
84	10	4	2	—	Pinions and slides
88	10	1	1	—	Pumps and plungers

Coming now to (b) we will consider propeller wheels. Manganese bronze is undoubtedly the finest metal for ship's propellers. It is eminently suited for propeller wheels with portable blades, and the modern practice is to have the boss, or hub made of cast steel and the blades of some high tension alloy like aluminum brass, delta metal or manganese bronze.

The analyses of two manganese bronze mixtures are given herewith:

	Per cent	Per cent
Copper	53.0	60.0
Zinc	42.0	38.0
Manganese	3.7	0.5
Aluminum	1.3	....
Iron	....	1.5

For solid propellers, that is, where the boss and blades are one casting, the best alloy, from a foundry standpoint, is the ordnance gun metal, copper 90, tin 10. This alloy is neutral to the iron or steel of the hull and corrosion is therefore slight.

In making the high-tension alloys previously mentioned, which are all in reality copper-zinc alloys with aluminum, iron or manganese additions, up to about 2 per cent, it is best to fix a standard, say 60 and 40, copper and zinc respectively, and add the strengthening elements in some intermediary form as, aluminized-zinc, ferro-zinc or cupro-manganese. The shrinkage of these alloys is great and with castings showing heavy sections, feeding heads are advisable.

TABLE B

Lead, per cent	Zinc, per cent	Tin, per cent	Antimony, per cent	Copper, per cent	
80	—	12	8.	—	Metallic packing
17	—	76	3.	3	Babbitt linings
4.5	75	18	2.5	—	Anti-friction castings, liners, etc.
—	76	18	—	6	Bearings
12	—	80	—	8	Plastic metal for pasting
38	—	42	17	3	Metallic packing for shavings
12	—	70	12	6	Hard metallic packing

Lastly, we have (c), formulas for other castings used about ships. We shall begin on the bridge and work gradually down to the lower decks. On the bridge we have the telegraph gear, the bell and the binnacle. The inside parts of the telegraph are of most importance; the cams and pinions require a strong gun metal of good wearing quality, copper 88, tin 9, zinc 3, or copper 88, tin 6, zinc 6. An excellent composition for telegraph and ship's bells is composed of copper 81, tin 17, zinc 2. On deck the fittings are mostly yellow brass. Copper 63 and zinc 37, with lead up to 3 per cent.

Rails, stanchions and port lights should be of good naval brass, copper 62, zinc 37 and tin 1, or Tobin bronze, copper 58, zinc 40, tin 1 and lead 1. In the saloon and cabins German silver is economical and effective for brackets, lamps, etc. A good composition which withstands the action of sea air well is made up of copper 56, zinc 24, nickel 18, lead 2. A cheaper quality, copper 54, zinc 30, nickel 16. A substitute alloy is copper 3, zinc 12, aluminum 84, phosphor-tin, 1.

In the engine room all sorts of alloys are required for pumps, condensers, dynamos, and auxiliary engines.

Plastic metal and anti-friction metal for linings should also find a place with the engine room stores. Some useful mixtures are given in Table *B*.

Nickel bronze.—A strong non-corrosive bronze suitable for ship's work, for ornamental castings or stampings, which has recently been patented, is made as follows: Make a preliminary alloy of iron 2 parts, copper 2 parts, zinc 1 part, and nickel 1 part. This is added to a "high-brass" alloy consisting of copper 54 parts, zinc 40 parts.

Shipbuilders' alloys.—A number of special shipbuilders' alloys are given herewith:

Manganese Bronze for Propellers, Bolts, Etc.

	Per cent
Copper	58
Zinc	38
Aluminum	1
Manganese-copper	3

Manganese Bearing Bronze

	Per cent
Copper	75
Tin	10
Zinc	4
Manganese-copper	11

Phosphor Bronze for Pinions, Brackets, Eccentrics, Etc.

	Per cent
Copper	86
Tin	7
Phosphor-copper	7

Hard Phosphor Bronze for Piston Rings

	Per cent
Copper	80
Tin	12
Phosphor-copper	8

Phosphor Bronze for Bearings

	Per cent	
Copper	79	75
Tin	9	5
Lead	8	18
Phosphor-copper	4	3

Nickel Alloys, White, Non-Corrosive, Strong and Free From Pinholes

		Per cent	
Copper	62	57	50
Zinc	20	20	35
Nickel	17.5	20	15
Aluminum	0.5	3	0.25

Delta Metal

	Per cent
Copper	50
Manganese-copper	5
Phosphor-copper	1
Zinc	43
Lead	1

Delta metal.—According to the Delta Metal Co., one of the special qualities of Delta metal which renders it of the greatest value for engineering purposes, lies in the fact that its strength is but little reduced by an elevation of the temperature. With steam at high pressures it is absolutely necessary that the engine parts and fittings exposed to the heat should be of a composition that renders them perfectly safe, even at such pressures as 40 atmospheres (about 600 pounds per square inch) and higher. At a pressure of 40 atmospheres the temperature is over 480 degrees Fahr., and, as will be seen by the following tests made by Professor W. C. Unwin, the cast Delta metal had at 506 degrees Fahr. lost only about 17½ per cent of its strength, while at 500 degrees Fahr., brass had lost over 38 per cent,

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Note:—German silver alloys require the very best metals and great care in their manufacture. Melt the copper and nickel together, add the aluminum and finish with the zinc.

phosphor bronze about 31 per cent, and gun metal about 33 per cent:

Breaking Strain, Tons per Square Inch

Temperature, degrees Fahrenheit,	Delta metal, cast	Brass	Phosphor-bronze	Gun metal
Atmospheric	23.89	12.45	16.06	....
210	....	....	....	11.66
270	....	....	14.16	....
310	23.36	....	....	....
350	....	11.83	12.26	....
380	....	....	....	12.26
406	....	....	....	11.06
410	22.48	....	....	....
430	....	....	12.41	....
440	....	....	....	12.30
450	....	10.40	....	....
500	....	7.69	11.10	7.84
506	19.68	....	....	....
550	....	7.68	....	....
590	16.00	....	....	....
600	....	....	8.17	5.22
615	....	....	....	4.82
635	12.70	....	....	....
645	....	3.23	....	....

Alloy for bells.—Special alloy for ship's bells: copper 90 parts, tin 10 parts, aluminum 2 parts. This is equal to cast steel in strength.

Plastic metal.—Richards' plastic metal for pasting: Tin 70 parts, antimony 15 parts, lead 10½ parts, copper 4½ parts.

Anti-rust metal.—Bailey's anti-rust gun metal: Copper 16 parts, tin 2½ parts, zinc 1 part.

Fittings for ships.—Yellow bronze for ship's fittings, stanchions, propellers, etc. (Patented): Copper 60 to 80 parts, zinc 20 to 40 parts, silicon ½ to 4 parts, tin 1 to 2 parts. This alloy may be forged or rolled hot.

Armor plate.—Armor plate, bronze, (Patent Alloy): Copper 85 parts, tin 4 parts, iron 6 parts, common salt 5 parts.

Damascus metal.—Damascus metal for bearings: Copper 76.46 per cent, tin 10.52 per cent, lead 12.56 per cent.

Aluminum alloy for automobile castings.—Aluminum 92 parts, zinc 6 parts and phosphor-copper 2 parts.

White brass, called "lumen bronze," for axle bearings.—Zinc 86 parts, copper 10 parts, aluminum 4 parts.

Plastic Bronze for locomotive bearings.—Copper 65 to 70 per cent, lead 23 to 30 per cent, and tin 5 to 7 per cent.

X

WHITE METALS

THE copper alloys bulk so largely in the manufacturing world that it is hard to get away from them. Taking the melting temperature of alloys as a means of division we have now to consider the more fusible, but none the less serviceable alloys, generally classed as *white metals.* Whereas most of the structural alloys, having a copper basis, melt in the neighborhood of 1,000 degrees Cent., the white metals and alloys require on an average less than one-half that temperature for their fusion. Outside of the ornamental white alloys—German silver, mock platinum, aluminum silver, and the like—and the white anti-friction alloys, there remains an important series of white colored metals having special casting qualities and high mechanical values. Such alloys as type metal, brittania metal, fusible metal, and solder do not belong properly to the general foundry practice. The best castings in these easily crystallized metals are obtained from chills, but owing to their fluidity, giving sharp impressions, and the expansion due to the presence of antimony or bismuth, they are eminently suited for mixing into pattern metals for sand molding as well.

The advantages of metal patterns as against wooden models are so great that their use is warranted for comparatively small lots of castings. Cast iron as a pattern metal is open to objection because of its brittle nature and its tendency to rust; nevertheless it may be freely used provided thin sections are avoided.

For small solid patterns (a) zinc-tin and (b) lead-antimony mixtures are favored. Usual proportions run (a) zinc

30 to 50 parts, tin 50 to 70 parts; (b) lead 78 to 87 parts, antimony 13 to 22 parts.

Solders, or lead-tin alloys are largely used for mounted pieces on molding machines; a good mixture in this class is lead 50 parts, tin 50 parts. These metals have the advantage of being cheap, but if the initial expense of getting up patterns for continuous use is not grudged, some of the tin-antimony alloys, or better still, the hardened aluminum alloys, will give better results as regards stiffness, wear, and conformity to design, besides being free from objection on the scores of shrinkage and clogging of the sand.

Properties for good pattern metals.—The properties necessary for good pattern metals are fluidity, low contraction, rigidity and strength. For ornamental castings or chased patterns, a fluid alloy having the important property of expanding on cooling would give the best results; Nos. 2, 3, 6, 7 and 8 would answer; No. 6 is a somewhat expensive metal but it is well suited for high class standard patterns; No. 1 will answer for castings requiring a certain malleability; No. 5 will stand a great deal of knocking about, as in rapping a pattern out of the mold; No. 4 is a splendid casting alloy but the contraction must be taken into consideration in making duplicates. The proportions in the above table need not be adhered to so strictly as would be the case with alloys required to undergo physical tests. Many modifications may be suggested by experience and the different requirements of the castings or patterns produced.

TABLE XXII

Pattern Metals

	Tin, per cent	Zinc, per cent	Antimony, per cent	Lead, per cent	Copper, per cent	Bismuth, per cent	Aluminum, per cent
No. 1	45	45	—	10	—	—	—
No. 2	17.5	—	—	75	—	7.5	—
No. 3	—	90	5	—	—	—	5
No. 4	3	85	—	—	10	—	2
No. 5	—	90	—	—	4	—	6
No. 6	80	—	20	—	—	—	—
No. 7	65	30	—	—	—	5	—
No. 8	16	12	12	60	—	—	—
No. 9	8	87	5	—	—	—	—

Aluminum as a pattern metal.—Aluminum has had a great vogue, recently as a pattern metal and it has much to recommend it. Very serviceable, accurate and conveniently handled patterns and match-plates, which are easily finished, result from the light aluminum alloys generally. Zinc-aluminum is a favorite combination nowadays because of the cheapness and strength of the product. An alloy of aluminum 75 parts and zinc 25 parts shows tenacity equal to 35,000 pounds per square inch and the cost pro-rata is much below the ordinary brass or white metal mixtures. Alloys of aluminum and tin are somewhat brittle and unstable, but the introduction of tin in aluminum-zinc alloys reduces the shrinkage and increases the resistance to corrosion.

Copper up to 10 per cent makes a convenient hardening agent for aluminum, but owing to the known tendency of the alloy to segregate on cooling, it is not advisable to introduce copper unless in conjunction with some other metal, as zinc, antimony, nickel, or tin. Some very useful alloys in this class are obtained by adding from 3 to 10 per cent standard German silver (melted) to the aluminum in the crucible. The 3 per cent alloy, first described by Dr. Richards, contains approximately ½ per cent each of nickel and zinc and 2 per cent copper. It gives a tensile strength in castings of 22,000 pounds, per square inch, with 3 to 5 per cent elongation, and has a fine white color.

TABLE XXIII

LIGHT ALUMINUM ALLOYS

	Aluminum, per cent	Zinc, per cent	Copper, per cent	Phosphorus, per cent	Tin, per cent	Antimony, per cent	Manganese, per cent
No. 1	90	8	1	—	—	1	—
No. 2	96	—	2.5	—	—	1.5	—
No. 3	90	2.5	—	—	—	—	7.5
No. 4	84	12	4	—	—	—	—
No. 5	84	12	2.75	1.25	—	—	—
No. 6	80	15	—	—	—	—	5
No. 7	77	17	6	—	—	—	—
No. 8	75	23	2	—	—	—	—
No. 9	75	23	—	2	—	—	—
No. 10	72	25	2	1	—	—	—
No. 11	*67	33	—	—	—	—	—

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*The cheapest of all the light aluminum alloys, sometimes called the Sibley casting alloy. Specific gravity, 3.8. Tenacity 24,000 pounds in sand castings, close-grained but brittle like cast iron.

Strong, light metals are in constant demand and other hardeners are being increasingly employed in the production of aluminum alloys and castings. Tungsten, chromium, titanium, silver, magnesium, and manganese have been used with good effects, but the alloys derived from any one of these metals and aluminum are all in the way of being specialties. For the most part such elements are either so expensive or so refractory as to be outside the range of practical foundry operations. The new alloy, "Meteorite" = Al + P, is easily produced by pulverizing the requisite quantity (4 to 6 per cent) of phosphor-copper and adding it to the molten aluminum. Similarly, manganese may be conveniently introduced in aluminum-copper alloys by using the commercial copper-manganese (30 per cent manganese).

Aluminum solders.—The soldering of aluminum and its alloys still presents some difficulty. Hiorns recommends that a deposit of copper be made upon the surfaces to be united prior to tinning and joining them together. Dr. Richards advocates the alloy invented by his father which contains aluminum 1 part, phosphor-tin 1 part, zinc 11 parts and tin 29 parts. Numerous patent aluminum solders and fluxes are on the market, but it must be acknowledged that cleanliness and the prevention of oxidation by some such protective coating as that recommended by Hiorns, or by the intervention of some reagent at the critical temperature, does more to insure a satisfactory joint than any supposed virtue in the solder applied. Good results have been obtained with ordinary "fine" solder, and bad results may be had with any of the patent solders. It is a question of mechanical skill and deftness.

White brass.—A large number of white alloys of different grades as to color and hardness are used for casting small busts, figures, and ornaments in chills and in sand molds. These alloys are principally used in the manufacture of cheap art bronzes and novelties which are lacquered. The workers employed in casting statuettes in chills acquire great dexterity in handling the latter. As soon as the cast is made and the desired thickness of metal is set (sometimes a mere skin of metal), they up-end the mold and drain out the liquid alloy remaining in the center. This leaves a thin, hollow casting with the outline of the bust, figure or design in perfectly regular proportions.

Sorel's alloys containing iron are also adapted for casting by this method. For producing zinc-copper alloys containing iron, two good plans may be followed: First, melt equal quantities of zinc and ferro-zinc together and add from 1 to 10 per cent of molten copper; or, second, melt 15 to 20 per cent Delta metal and make up by adding plain zinc. Most of the white brasses comprised in the range of copper 20 to 45, and zinc 45 to 80, are appreciably improved by a further alloy of aluminum, 2 to 5 per cent. The metal exhibits a higher degree of homogeneity and it is more durable and less liable to corrosion. Some typical white brass mixtures are given in Table XXIV.

TABLE XXIV

White Brass Mixtures

	Zinc, per cent	Copper, per cent	Tin, per cent	Aluminum, per cent	Lead, per cent
No. 1	66	33	—	—	—
No. 2	57	43	—	—	—
No. 3	56	36	6	2	—
No. 4	68	24	6	2	—
No. 5	80	20	—	—	—
No. 6	91	8	—	—	1
No. 7	90	3.5	3	—	3.5
No. 8	88	10	1	1	—
No. 9	80	4	16	—	—
No. 10	74	6	20	—	—
No. 11	28	57	15	—	—
No. 12	50	40	5	5	—

Nos. 1 and 5 are hard, but easily worked; Nos. 2, 8, and 12 are somewhat malleable and can be pressed; No. 11 makes a good white brazing solder; Nos. 3, 4, 6 and 8 are excellent alloys for chill castings; Nos. 9 and 10 are well suited for patterns provided the usual allowance is made for shrinkage; No. 7 is a cheap mixture for ornamental castings.

A metal having a lustre equal to the best German silver but without nickel consists of copper 50 parts, manganese-copper (30 per cent manganese) 40 parts, zinc 14 parts and aluminum 2 parts.

TABLE XXV

Special Mixtures

		Tin	Antimony	Lead	Copper	Bismuth
No. 1.	Plastic metal	70	15	10.5	4.25	.25
No. 2.	Plastic metal	80	—	12	8	.5
No. 1.	Metallic packing	42	17	38	3	—
No. 2.	Metallic packing	36	8	56	—	—
				Tin	Nickel	Platinum
No. 1.	Bell metal			19	80	1
No. 2.	Bell metal			17	82	1
			Copper	Zinc	Nickel	Ferro-manganese
No. 1.	White bronze		68	21	9	—
No. 2.	White bronze		40	—	—	60
				Copper	Zinc	Iron
	White brass			9	89	2
				Aluminum	Zinc	Manganese-copper
	Special pattern metal			90	3	7

Art metal.—Art metal for casting small figures, plaques, etc.: Zinc 90 parts, aluminum 5 parts, antimony 5 parts. This alloy is also an excellent solder for aluminum, fluxed with sal-ammoniac. Another similar mixture consists of zinc 100 parts, with rosin 2 parts, nickel 1 part. This may be used for hard soldering aluminum as well as for art castings.

XI

SOLDERS, NOVELTY METALS, ETC.

BESIDES the alloys in everyday use for castings and those for manufacturing by rolling and other mechanical processes, many metals are mixed and prepared for other important purposes, as solders, tempering baths, plastic metals, fusible metals, shot, dental stopping, anodes for electroplating, metallic shavings and granulates for steam packing and brazing.

Soldering is the process of uniting two metallic faces by means of a fusible metallic cement. The solders are classed as *soft* or *hard,* according to the temperature at which they melt. Soft solders fuse at comparatively low heats; hard solders fuse only at a red heat. In every case the solder must be more fusible than the bodies to be soldered. As a rule the solder approximates in color, composition and properties to that of the metal to be soldered. Sometimes two pieces of the same

TABLE XXVI

SOFT SOLDERS

Parts		Melts at degrees Fahr.	Suitable for baths for tempering	Remarks
Tin	Lead			
1	25	558	Saws and Springs	
1	10	541	Watch springs	
1	5	511	Hatchets and planes	Very coarse
1	3	482	Chisels and Knives	Common solder
1	2	441	Razors	Plumbers' sealed solder
1	1½	412	Lancets	Zinc solder
1	1	370		Tinsmith's solder
1½	1	334		Lowest melting point of series
2	1	340		Fine solder adapted for brass, steel, etc.
3	1	356		Fine, hard, tenacious metal
4	1	365		Common pewter
5	1	378		
6	1	381		
5	3			Tinning metal for copper

metal are soldered by heating the edges by means of a blowpipe and kneading them into one. This is termed *autogenous soldering,* but only those metals that assume a pasty condition before melting, like lead or aluminum, are amenable to this process. Soft solders are graded as *fine, medium* or *common,* according to the content of tin. The ordinary soft solders contain only tin and lead, the proportions being varied to suit the work. Table XXVI gives some of the best examples.

Soft solders for delicate ornamental pieces require to be more readily fused and more fluid than the alloys given in Table XXVII. Pewterers must employ solders that melt below 300 degrees Fahr., hence we find alloys for their work contain bismuth, cadmium or arsenic in addition.

Pewter.—Pewter is a tin and lead alloy hardened with small additions of antimony and copper. The best qualities of pewter are akin to Britannia metal, which is a tableware alloy with some resemblance to silver.

TABLE XXVII

PEWTER, BRITANNIA METAL AND FUSIBLE SOLDER MIXTURES

Tin	Antimony	Copper	Bismuth	Lead	
100	8	2	2		Plate pewter
100	17				Best pewter
75 to 94	5 to 25	1 to 9	1 to 3		Britannia metal
59			12	29	Fusible solder
20			50	30	Melts at 197° Fahr.
30			20	50	Melts at 212° Fahr.
1			1	1	Melts 284° Fahr., very fluid

The examples in Table XXVII are given as typical alloys in each class. The wide range of proportions in britannia metal allows considerable latitude in working the metal by rolling, hammering, stamping, spinning or casting in chills.

The fusible metals become still more fusible when additions of cadmium or mercury are made. Thus, Wood's alloy contains 5 parts bismuth, 2 parts tin, 2 parts cadmium and 4 parts lead, and fuses at 158 degrees Fahr. Another alloy which melts at the same temperature is Lipowitz's. It contains cadmium 3 parts, tin 4, bismuth 15, lead 8. The alloys are very useful for soldering tin or lead in thin sections, and britannia metal; also for fine castings, impressions of dies where sharpness is required, and for soldering in hot water.

An alloy for fusible teaspoons is composed of bismuth 8 parts, tin 3, lead 5, mercury 1 to 2. By adding 1-16 its weight of mercury to Wood's alloy, a new compound, fusible at the temperature of the human body, is obtained. Casts are sometimes taken of small animals with one of these alloys. The animal substances are destroyed by a concentrated solution of caustic potash, and the metal remains.

Dentists' amalgams.—Alloys, or rather amalgams for filling teeth, should melt in hot water and set hard at about 70 degrees Fahr. Dentists' alloys for this purpose usually have mercury 74 to 78 parts, cadmium 22 to 26 parts. However, gold amalgams are most in favor for this purpose.

Before we leave the fusible alloys there is a novelty in amalgams that deserves notice. It is called Mackenzie's amalgam. This amalgam, which is solid at ordinary temperatures, becomes liquid by simple friction. It may be prepared as follows: Melt two parts of bismuth and four of lead in separate crucibles, then throw the melted metals into two other crucibles each containing one part of mercury. When cold these alloys are solid, but will melt when rubbed together.

TABLE XXVIII

GOLD SOLDERS

	Aluminum	Tin	Zinc	Gold	Silver	Copper
For 9 carat gold, according to Gee, the composition approximates	..	..	..	1	2	1
For 14 carat gold, according to Gee, the composition approximates	..	..	..	3	2	1
For 16 carat gold, according to Gee, the composition approximates	..	..	..	9	2	1
For 18 carat gold, according to Gee, the composition approximates	..	..	..	10	5	1
For best solder, the composition approximates	..	..	..	25	9	6
For easy melting solder the composition approximates	..	..	..	12	7	3
For very easy solder the composition approximates	..	..	5½	11½	54½	28½
For dental articles the composition approximates	2	..	..	5	1	1
For aluminum blow-pipe solder	2	6	3	..	1	1

Hard solders.—Passing now to the *hard* solders, we come to alloys melting in the proximity of 800 degrees Fahr. and upward, and possessing greater variety in color, texture and mechanical properties. Hard solders are prepared in various forms. For the precious metals the alloys are cast into strips, rolled out thin and cut with hand shears, or pressed into suitable pieces, termed "pallions;" but if the surfaces to be joined are inaccessible to these pallions, the solder is filed into dust fine enough for all requirements.

Hard solders for gold are composed of gold, silver and copper in proportions to suit the color, hardness and fusibility of the standard alloys, as shown in Table XXVIII.

Silver solders.—Silver solders are used for all kinds of metals and alloys, steel, brass, silver alloys, gold alloys and German silver alloys. The fine solders contain silver and copper only. Medium solders contain zinc as well. Arsenic and tin are sometimes added to give greater fusibility, and for German silver articles nickel and brass have a place. Zinc is generally introduced in the form of brass, but it is important that the alloy should be free from lead.

TABLE XXIX

SILVER SOLDERS

	Silver	Copper	Zinc	Brass	Tin	
1	4	1	..	..	..	Ordinary hard solder
2	2	..	..	1	..	
3	3	..	..	1	..	Tenacious, ductile
4	5	..	..	1	..	Soft, for fine metal
5	8	0.5	1.5	..	..	Medium
6	8	0.25	1.75	..	..	Easy melting
7	6	2	1	..	0.25	
8	1	0.75	..	32	2	Soft
9	32	..	..	4	1	Hard
10	4	1	..	1	..	Common brass silver solder
11	1	..	..	Arsenic 0.25	1	Very easy solder
12	2	..	..	" 0.25	0.75	
13	8	5	..	..	..	For steel
14	3	1	..	..	..	For cast iron
15	2	3	1	Nickel	..	
16	..	35 to 45	40 to 57	8 to 12	..	For German silver
17	..	38	50	12	..	For steel

The solders are generally used in the form either of fine spangles, dust, granulates, shavings or pallions, and the composition is varied to match the color and other characteristics of the work to be joined. The alloys are all white; Nos. 1 to 8, Table XXIX, are for fine silverware or ornamental manufactures; Nos. 9 to 11 are for tableware and fine brass articles; No. 12 is for filigree work.

Solders for glass and pottery.—No. 1.—Tin 100, zinc 3; cast into thin rods for use; heat the edges and apply.

No. 2.—Amalgam, 70 per cent mercury; make a soft alloy of tin granulate and copper dust with sulphuric acid; add mercury, wash out the acid when mixed; when solder is to be used heat and knead in an iron mortar and apply when plastic.

Fusible hard solder for aluminum alloys.—No. 1.—Nine parts standard phosphor-bronze (no lead), 11 parts tin, 100 parts aluminum.

No. 2.—Mix 8 parts standard phosphor-bronze (filings), 2 parts tin and 8 parts borax.

No. 3.—Alloy copper 3 parts, aluminum 9 parts, zinc 14 parts and granulate; use cyanide of potassium for a flux.

Soft solders for aluminum and alloys.—No. 1.—Zinc 25, aluminum 6, tin 69; melt zinc and aluminum together and add the tin; flux with Venetian turpentine or tin the work before soldering.

TABLE XXX

Brass Solders

	Copper	Zinc	Tin	Silver	Suitable for
No. 1	58	42	—	—	Copper pipes
No. 2	57	43	—	—	Brazing metal flanges
No. 3	54	45	1 to 3	—	Gun metal
No. 4	53	47	—	—	Light flanges
No. 5	50	50	—	—	Brass solder
No. 6	47	52	1	—	Brass solder, fusible
No. 7	72	18	4	—	Malleable
No. 8	46	50	4	—	Half white, fusible
No. 9	58	28	—	14	White, refractory, for steel
No. 10	24	52	—	24	White, refractory, for copper
No. 11	10	—	—	30	White, fusible
No. 12	5	3	—	2	White, fusible

No. 2.—If ordinary soft solder is fused with one-half, one-fourth or one-eighth of its weight of zinc amalgam a more or less hard and fusible solder is obtained, which may be used to solder aluminum to itself or to other metals. Zinc amalgam as used for electrical machinery is made by melting two ounces of zinc in a ladle, then removing from the fire and stirring into it five ounces of mercury (previously heated). Stir until cold, then powder it and keep in a tightly corked bottle.

Hard solders for brass and alloys.—By far the most important series of hard solders are those for copper and brass—braziers' solders. They go under the trade name of spelter solders, so-called because of the high proportions of zinc or spelter in their composition. To make uniform grades of brazing solder requires careful melting and mixing of the proper quality of metals, and they should be poured at the proper temperature. As a rule a portion of the zinc is mixed in in the form of fine sheet or wire brass. The copper-zinc solders have a bright yellow color; a tendency to gray or blue is a sure indication of impurities in the metals, such as tin, iron, lead, antimony or phosphorus. Sometimes tin is added to increase the fusibility of the solder. It is always advisable to have the composition of the solder as near to the strength of the metals to be brazed as practicable. Copper, iron, gun metal and all the brass alloys have different fusibilities and mechanical properties, so that a much stronger joint is made when the solder approaches the qualities of the metal treated.

To insure perfect soldering, or brazing, cleanliness is a first essential, and in almost every case the solder and the metal to be soldered are covered with a flux to ward off the oxygen of the atmosphere and to assist in the union of the metals.

Brazing solder is nearly always used in the granulated form, and its manufacture is effected either by pouring the molten alloy from a height, or through a strainer, into water, or by casting it into slabs or ingots and pulverizing it as soon as set. Some manufacturers have machinery for pulverizing the highly heated ingots and the grains pass through screens of several gradations. This gives grains of regular size and a choice of grades for light or heavy work. The discoloration and oxide due to the exposure of the hot metal in the atmosphere is removed by dipping the granules in a weak pickle and drying off immediately. But coppersmiths place the cast solder before the machine-made article; it seems to stand hammering much better, and it takes less borax to flux it, probably because the grains are globular, Fig. 14, No. 3, while the pulverized is like spangles, Fig. 14, No. 1.

To see the pouring of a heat of brazing solder is to witness one of the most interesting spectacles the brass foundry affords. The metal is granulated by being poured from a height into a tank of clean water. Owing to the high content of zinc

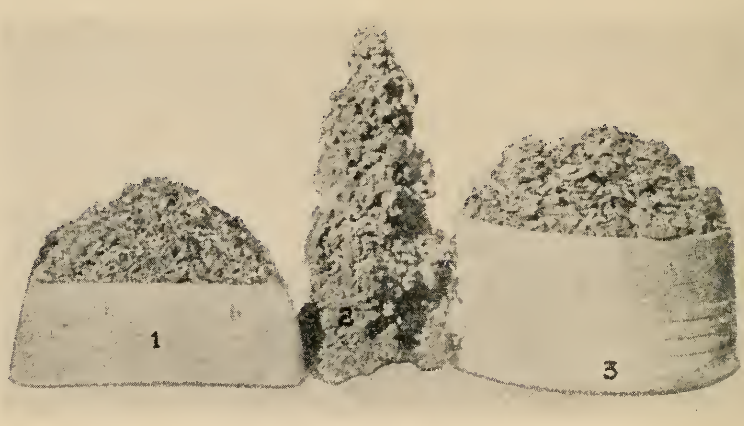

Fig. 14—Brazing solders

Fig. 15—Method of granulating brazing solder

a glowing incandescence, some blue haze and a great deal of philosophers' wool permeates the foundry during this operation. You stand gazing at the thin red line as it falls hot from the crucible into a water grave—no, that is too poetical—a barrel of water is the actual fact. You admire the courage of the caster perched on some rickety, temporary staging, placed on the top of a drying stove or a pile of molding boxes, when suddenly the illumination ceases, the heat is poured off, and, feeling a choking sensation in the upper regions of the chest, you rush for the door and miss the best part, which is to see the nice, bright, round grains of metal taken from the tank, washed under the tap and dried off ready for use. Fig. 15 is an attempt to illustrate the pouring, but it would require a cinematograph to show the effect of the fine stream of molten alloy hitting the water, the rising steam, the whirling smoke, the snow-like ZnO, and the pyrotechnic display. The height from which the metal is poured and the rate of pouring regulates the size of the grains. Twelve feet was the fall in this case. Sometimes a plumbago strainer or colander is fixed in a frame immediately over the tank; the metal is poured into this and drops through in regular-sized grains. The only objections to this process are the skulls left in the strainer and the expense. Another method is to pour the metal upon a cast iron ball barely covered with water in a shallow dish. On striking the ball the

TABLE XXXI

NON-OXIDIZABLE BRONZES

	Copper	Zinc	Aluminum	Phosphor-tin	Bismuth	Nickel	Murcury
1	2	15	80	1	—	—	*2
2	2	12	85	—	—	—	1
3	1	8	90	—	—	1	—
4	88	8	2.5	1.5	—	—	—
5	85	1	9	4	—	—	1
6	90	6	4	—	0.5	—	—
7	91.5	1.5	0.03	6.7	—	—	0.07
8	40	20	—	14	0.75	27	—
9	60	17.25	1	12.5	0.75	8.5	—
10	72	22	2	4	—	—	—
11	24	68	2	6	—	—	—
12	47	21	—	1	—	31	—

---

*Alloys containing mercury, arsenic, antimony or zinc show considerable loss of those elements by remelting, so that care must be taken not to overheat the alloy or remelt it without adding new metal.

metal scatters into small pieces and falls into the water. But the finest and most uniform product of all is obtained by arranging a horizontal pipe in connection with a force pump. The cock on the pipe is opened so that a jet of water is thrown across the tank which is to receive the alloy. Upon this jet of water the molten metal is poured. The force of the water may be regulated so as to give grains of a determined size, within certain limits. Some skill is required in the pouring by all of these methods if uniform grains are desired. The metal must fall in a regular, thin stream, otherwise on emptying the tank, a conglomerate, similar to No. 2, Fig. 14, will result.

TABLE XXXII

Miscellaneous Alloys

	Copper	Nickel	Silver	Aluminum	Tin
Rozine for jewelry, No. 1	43	32	25	—	—
Rozine for jewelry, No. 2	—	40	10	30	20
Rozine for castings, No. 3	—	3	—	87	10
Rozine for castings, No. 4	1	3	—	96	—
Rozine for springs, No. 5	—	—	6	94	—
New bell metal	87	—	—	2	11
		Lead	Antimony		
Acid bronze	76	9	5	—	10
			Cobalt		
Cobalt bronze	40	—	50	10	—
			Manganese		
Heusler's magnetic alloy	85.5	0.5	6	8	—
			Zinc		
Brass to expand by equal heat with iron (Bolland)	79	—	15	—	6
		Nickel		Platinum	
Platinum bronze	42	31	22	5	—
Platinum bronze	—	100	—	0.5	—
Anti-rust alloy for stop cocks	7	—	72	—	21
Anti-friction brasses	5	1	80	—	14

In no case should the solder be left over night in the water; it should be dried off at once to avoid unnecessary oxidation, and for the same reason it should be kept in air-tight tins. Any attempt to pour a second heat into the same water would result unsatisfactorily. The oxides from the first pouring, which gather like a scum on the surface of the water, and the heat of the water itself would be fatal to the best results. The average composition of brazing solders varies between copper, 58 to 40 parts, and zinc, 42 to 60 parts, the fusibility of the alloy being in proportion to the amount of zinc present, 1,150 degrees Fahr. being approximately the melting point of No. 5, Table XXX.

For those who prefer to use mixed metals a convenient mix for brass solder is to melt 30 to 40 pounds brass wire or sheet and add to this 10 pounds of virgin zinc. Copper tubes are now manufactured having from 2 to 3 per cent aluminum alloy. The British Admiralty adopted the use of these for steam pipes and copper fittings, because of the relatively high tensile strength and the advantages offered by increased burdens, or the diminution of weight in similar structures. An excellent blow-pipe solder for this class of work is M. Mourey's, which contains tin 6 parts, zinc 3 parts, aluminum 2 parts, copper 1 part, silver (optional) 1 part.

To solder without heat.—Brass filings 2 ounces, steel filings 2 ounces, fluoric acid ¼ ounce; put the filings in the acid, apply the solution to the parts to be soldered. After thoroughly cleaning the parts in contact, dress together. Do not keep the fluoric acid in glass bottles, put it in lead or earthen vessels.

Novelty metals.—About the middle of the nineteenth century the introduction, for a set purpose, of the metalloids in metallic alloys, constituted a novelty in practical alloying. Later, when aluminum became a comparatively cheap product, several new series of useful and novel alloys made their appearance, and with the advances of electric engineering, the conductivity and magnetic power of metals and alloys were put into new relations. The latest novelty to be recorded is the commercial production of some alloys by electro-deposition. There is still ample scope for the invention of new alloys and more scientific methods of making and manipulating them, and it is along these lines that the best work will yet be done. Some metals in alloys suffer from over-popularity such as, aluminum, lead, phosphorus, zinc, etc. Aluminum, because of its low specific gravity; lead, because of the weight and economy of its use in alloys; phosphorus, because of the fusibility and over-rated refining influence it has on dirty metals, and zinc, because of its cheapness and toughening effect in other metals. The abuse of these metals is well known to those who handle ready-made alloys for the production of castings.

Time was when phosphor bronze was held in high esteem, but now, because of the indiscriminate use of phosphorus and lead, it has fallen out of line. Aluminum was all the rage for a while as a mixer, deoxidizer, strengthener and cure-all in iron, steel, copper and alloys, but it was over-exploited in these particular lines, and the true, legitimate uses of the metal are only beginning to be found out. Perhaps the art section of modern industries is responsible for more of the novelty metals than any other branch.

Metals have always been in use for ornamentation, but the artistic influence of alloys in recent times has tuned up the general style of decorative metal work, and bright chromatic effects are giving place to the solid, old-fashioned, monotonous design of the wrought-iron period. With alloys we can have lightness, cheapness, elegance, strength and variety of color scheme combined in the newest are.

A new *argentan* which resembles silver and may be worked like German silver contains copper 70 parts, nickel 20 parts, zinc, 5.5 parts and cadmium 4.5 parts. Some cheap alloys, fusible, white, close-grained and in every way suitable for casting objects of art are made as follows: Melt three parts of tin in a crucible, heat two parts mercury in a hand ladle and add carefully to the barely molten tin; pour out into ingots. Add five per cent of this tin-mercury alloy to the ordinary aluminum-brass mixture—copper 57, zinc 42, aluminum 1. The resulting alloy has a beautiful pale pink color when polished, and it may be used alone or as a hardening composition in white metals.

TABLE XXXIII

Magnesium Alloys

		Copper	Nickel	Magnesium	Aluminum	Tin	Zinc
Strong........................	No. 1	1.76	1.16	1.60	95.45		
Soft, rolls well................	No. 2	0.21	0.3	1.58	94.0	3.15	0.7

Alloys containing mercury.—Though scientifically of interest, alloys containing mercury are seldom used in the industries. Even when the difficulties of combining a metal, which is liquid at ordinary temperatures with the refractory metals are overcome, the permanence of the alloy is not easily assured, and in remelting, the mercury content will be considerably reduced.

One mixture which has the advantages of small shrinkage and high luster consists of one part of the hardening to two parts of zinc. Approximate analysis showed the finished proportions to be: Zinc 81.48, aluminum 0.40, mercury 0.72, tin 1.0, copper 16.22. Other non-oxidizable metals containing mercury are given in Table XXXI.

These alloys vary in color from white to a deep golden hue; Nos. 1, 2 and 3 are aluminum alloys with the luster of silver and considerable hardness and elasticity; Nos. 4, 5, 6 and 7 are variations of the ordinary bronze alloys; Nos. 8 and 12 are nickel bronze, hard and sonorous; No. 9 is still white and malleable.

New magnesium alloys are coming into use, and the composition of two is shown in Table XXXIII.

SPECIAL MIXTURES

Special anti-friction lining metal.—Tin, 53, lead 33, copper, 3, antimony 11; melts at 295 degrees Fahr.; specific gravity, 7.23.

E. Murman's improved Magnesium.—Aluminum 100 parts, magnesium 1 to 10 parts, zinc 1 to 20 parts; the zinc overcomes the difficulty of obtaining sound castings and the tenacity is not reduced.

Gun metal for piston rings and springs.—Copper 83, tin 10, zinc 7; very elastic.

Cheap white alloy for art castings.—Aluminum 78, zinc 12, copper 8, tin 2; fine luster.

Red brass for fine ornamental castings.—Copper 82.5, zinc 16.25, bismuth, 1.25.

Hard solder for bell metal.—Brass 40, copper 10, tin 15.

Hard white brass.—Tin 67, antimony 11, copper 22.

Alloy for scientific instruments, named Zisikon.—Aluminum 80 parts, zinc 20 parts.

Brass, tough alloy, will bend double.—Copper 64, zinc 33, silicon-copper 3.

A new alloy for bearings has been patented by Hans Kreusler, Wilmersdorf, Germany. It is said to have a very low coefficient of friction and consists of cadmium 45, zinc 45, and antimony 10.

Charpy has found the alloy containing 83 per cent tin, 11.5 per cent copper and 5.5 per cent antimony to possess the greatest compressive strength. Locomotive bearings are generally filled with metal very close to this composition.

XII

FLUXES FOR ALLOYS

FLUXES are the re-agents of the smelter and the proper use of fluxes is of the highest importance in the production of metals from the ores. Most fluxes act both chemically and physically; they are acid or basic according to the oxygen ratio of flux and gangue. Acid fluxes mostly silicates, are employed to act upon basic materials and *vice versa*. Alkaline fluxes are chiefly used in refining metals. In the foundry, where only refined metals are used, there is not the same scope or necessity for using fluxes.

Many of the so-called neutral fluxes act simply as protective coverings to the surface of the metals in the process of melting. Charcoal, coke dust, lamp black and such highly carbonaceous bodies give excellent protection in the reduction of brass and gun metal alloys. In charging the crucible the very first ingredient should be a handful of charcoal or coke dust; then as the metal melts and rises in the crucible, the surface of the bath is protected from the oxidizing influence of the atmosphere. In this way the true character of the alloy is maintained, whereas by careless treatment, overheating or prolonged melting in contact with the fuel and products of combustion, the best of metals may be rendered worthless.

It is worthy of note that metals, which are cast, always show their natural defects in the casting, but metals which undergo mechanical treatment, as rolling, forging, etc., may have similar defects entirely removed or at least remedied by the process.

All the good work that can be put into a casting should therefore be done before the metal enters the mold. The preparation of alloys for casting requires greater precautions than are necessary in the case of simple metal, and the difficulties increase with every added component, unless there is chemical affinity to assist in the combination.

Even with the most careful melting the metals are partially oxidized and gases are occluded or absorbed. To free the metal from these oxide compounds and gases in solution, fluxes capable of re-dissolving the oxides and removing the gases are introduced. In some instances it is also desirable to remove foreign metals known to be present in the alloys as impurities.

To free brass turnings from iron, salt them well, moisten thoroughly, and after a few days wash with running water. Of course, if old metals are used many more impurities are liable to be introduced than with new metals. Scrap brass has always some impurity clinging to it, grease, paint, sand, solder, red lead, cement, etc., and the effect of these contaminations is to deteriorate the physical properties of the metal.

A suitable flux may to a large extent remove the dross and counteract the baneful effects of the impurities, but if uniformity is desired in an alloy as a regular product, scrap metals and their attendant faults and fluxes should be barred.

Fluxes for alloys.—Following is a list of the most common fluxes for alloys:

For brass.—Potassium carbonate; this consists of pearl ashes mixed with damp sawdust.

For brass.—Potassium sulphate; this consists of sal-enixum mixed with charcoal.

For brass.—Salt cake; this consists of crude sodium carbonate 5 parts, silica (white sand) 15 parts, coal dust (anthracite) 5 parts, bone ash 20 parts. Mix, cover the surface of the metal, stirring it in before bringing to a heat.

Gun metals.—Equal parts of crude tartar and nitre burned together.

Gun metals.—Sodium chloride (common salt) is a useful flux in reverberatories; it forms a fusible compound with antimony and arsenic, thus removing these undesirable elements from the alloy.

Gun metals.—Nitre, 3 parts, argol 2 parts; recommended by T. D. Bottome.

Gun metals.—Silica; great hardness and ductility may be given to red brass without having recourse to phosphorus, by mixing in with the other metals, two per cent of finely powdered green bottle glass, placing it at the bottom of the crucible; if the alloy is for parts of machinery and to be tooled add one per cent manganese dioxide (MnO_2). The metal is rendered very fluid and close-grained.

Babbitt metals.—Sal-ammoniac (ammonia chloride); this substance is decomposed by the metals at comparatively low temperatures, forming metallic chlorides and liberating free ammonia.

Babbitt metals.—Tallow or fat of any description and rosin; these substances ignite and liberate gases, which unite with the contained oxygen, thus acting as reducing agents on the metallic oxides.

Brazing metals.—An improved flux consists of boric acid and sodium carbonate in equal parts; this is used instead of borax; it does not intumesce like the latter.

Aluminum alloys.—Benzine, resin, cryolite; fluxes proper are to be avoided with aluminum, especially sodium compounds; they injure the alloy by dissolving the walls of the crucible and introducing infusible silica and iron compounds; overheating is a prolific cause of trouble with the light alloys.

Nickel alloys.—Plaster of Paris and nitre equal parts to be stirred in five minutes before casting.

German silver.—A special flux for German silver consists of silica sand 3 parts, ground marble 5 parts, borax 1 part, salt one-half part; mix with an equal quantity of powdered charcoal.

Britannia Metals.—Stearic acid heated and applied to the mold is a preventive for faintness in fine chilled castings in soft alloys.

Brass sweepings.—Mr. E. S. Sperry speaks highly of plaster of Paris ($CaSO_4$) as a flux for reducing brass ashes, skimmings, buffings and grindings. Such finely divided particles are generally productive of more dross than metal if melted in the ordinary way. This is a cheap and thoroughly efficient flux.

Copper.—The purification of copper has received considerable attention; zinc oxide and charcoal added to molten copper are helpful in producing sound copper castings. These substances are mixed with molasses water to a stiff paste, formed into balls and dried. When the copper is just melted one of the balls is dropped on the surface; it covers the metal and the zinc in the mass combines with any oxygen present. Silicon-copper is the best deoxidizer for cast copper, but it comes under metallic fluxes.

Copper alloys.—The following mixture for improving copper alloys was the subject of a patent: Iron peroxide 33 parts, manganese peroxide 1 part, magnesium carbonate one-half part, alum 18 parts, silica 3½ parts, borax 4 parts; mix and stir well into the metal.

NH_4Cl

Zinc alloys.—Sal-ammoniac is the best flux and the method of using it is to sprinkle it upon the surface of the metal while it is molten.

From the foregoing it may readily be believed that there is no lack of variety of fluxes for alloys, at the same time it cannot be too strongly emphasized that the duty of a flux in foundry practice is to purify the metal without entering into combination with it. Such a flux is not easily obtained and some of those here given are open to serious objection because of their corrosive action on the linings of ladles and crucibles resulting in the loss of metal in forming slag and in some cases adding new forms of impurity to the metal treated.

In the refinery, fluxes are essential to liquify and dissolve away refuse matters associated with the metals, and their effect as solvents may generally be stated in the terms of an equation, but in the foundry, where only finished metals are dealt with, oxidation is the one thing to be guarded against.

In the refinery, fluxes are essential to liquify and dissolve metallic additions has become universal. Much of the excellence of our modern alloys is due to small additions of elements, which to some extent form chemical combinations with the mixture. We have already admitted that the chief use of a flux in foundry practice is to remove certain faults introduced with scrap metals. Now, it seems that object can be attained, and the alloy improved, by the use of some metallic flux (?), with greater ease and certainty, than by the application of the salts and radicals previously mentioned.

Tempering metals.—These *tempering metals,* as they are now called, must be used with judgment. Most of them might be called concentrated alloys. They include the following:

Phosphor-copper,	which	contains	10 to 20 per cent phosphorus
Phosphor-tin,	"	"	5 per cent phosphorus
Phosphor-aluminum,	"	"	5 per cent phosphorus
Manganese-copper,	"	"	30 per cent manganese
Ferro-manganese,	"	"	25 to 50 per cent manganese
Ferro-aluminum,	"	"	10 per cent aluminum
Ferro-zinc,	"	"	5 per cent zinc
Aluminized-zinc,	"	"	2 per cent aluminum and phosphorus
Silicon-copper,	"	"	15 per cent silicon
Arsenic lead,	"	"	2 per cent arsenic
Antimonial lead,	"	"	20 per cent antimony
Magnalium,	"	"	2 to 10 per cent manganese and 10 per cent aluminum
Zinc-aluminum	"	"	3 to 33 per cent zinc

The use of these specially prepared, and in most cases, concentrated alloys, has advanced very rapidly in recent years. Phosphor-copper and phosphor-tin were among the first of the new tempering metals to be used for fluxing or to impart special properties to alloys. The vigorous purifying effect of these phosphides on bronze are well known and appreciated, but the most important feature in this, as in most of the newer improvements in alloys, lies in the fact that the structure changes, pointing to a condensation of the alloy, and giving increased density, tenacity and fusibility.

Phosphorus.—For many years phosphorus was the cure-all of the brass founder. It livened up dull metal by dissolving the copper oxide, which forms so readily in copper alloys; it also increased the utility of lead in brass and gun metals and it was supposed to turn old, inferior metals into castings of just as fine appearance and as good practical value as could be obtained from new metals.

On this supposition the mistake was often made of adding an excess of phosphorus. It was a fatal mistake. Phosphorus is a weakening element in any alloy if it remains in solution. For this reason only so much as may be necessary to reduce the oxides and remove impurities generally from 0.5 to 1 per cent is desirable to flux brass or gun metal, while as a tempering agent in bronzes the content of phosphorus should in no case exceed 2 per cent.

Owing to the commercial production of these tempering metals in definite proportions it is an easy matter to combine the exact quantities of the temper desired.

Aluminum.—Next to phosphorus, aluminum is the most popular flux or tempering metal for casting alloys. For some years past it has been quite the rage. But it also has proved a dangerous element when it has been used indiscriminately.

Phosphorus is most beneficial in copper-lead alloys, and least active in copper-zinc alloys; aluminum on the other hand is positively harmful in copper-lead mixtures and most effective in strengthening copper-zinc alloys. The subject of metallic reactions is one which deserves the fullest investigation and the active properties of aluminum in metallic combinations are specially interesting.

I am quite convinced that the writer of the advertisement for a metal concern knew something when he penned this: "It (Al) operates to increase the chemical affinity between the different elements of the mixture and tends to *determine* the copper or higher colored elements to the surface." That statement alone did not carry conviction; but my own experience and the knowledge of a process by which a cast iron alloy with copper and aluminum could be made to produce castings having the appearance of brass, led me to the conclusion that aluminum could either precipitate the copper or alloy with the copper, and because of its low specific gravity and high specific heat this copper-aluminum alloy appeared on the surface of the casting.

The value of aluminum in brass alloys is unquestioned. It increases the tenacity of brass by more than one-third and gives a closer grain and a higher color. It reducess the corrosive power of the atmosphere on brass and it is an economical mixer in quantities from 0.5 to 4 per cent. The best method of combining the aluminum is in the form of aluminized-zinc.

Manganese.—Manganese is another splendid deoxidizer for copper alloys. Metallic manganese is hard to reduce, therefore an alloy of copper and manganese is the best medium for introducing the temper. Usually about two per cent manganese is added to the ordinary alloys. Ferro-manganese, ferro-aluminum, and ferro-zinc are frequently used in the production of manganese bronzes and sterro metals.

Certain metals are known to react upon each other in the heat to promote fluidity, as silicon, phosphorus, aluminum, and manganese in copper alloys, hence, the special preparations silicon-copper, etc., have come to be regarded as metallic fluxes in the brass foundry.

Arsenic.—The element which approaches nearest to the action of a flux is arsenic because it promotes the union of metals that would otherwise be difficult to mix. Arsenic bronze, now used for railway brasses, is a good example. The compositions average: Copper, 80 parts; tin, 10 parts; lead, 10 parts; the arsenic added equals 8 parts. Arsenic is also useful in helping to carry a higher percentage of lead in zinc alloys.

Fluidity of metals.—The fluidity of metals is variable, and as a general rule the fluidity of alloys is greater than that of the individual metals. Zinc or copper melted by themselves are comparatively sluggish, whereas brass, the alloy, is a very fluid metal. Zinc alloyed with antimony is more viscid than plain zinc while an alloy of copper and antimony is remarkably fluid. Aluminum has better flowing power when barely melted than at higher temperatures, but immediately when it is alloyed with some other metal this characteristic loses force.

Instances could easily be multiplied showing that small additions of metals in alloys,—so small as not to class them as alloying metals—have the same purifying effect as have fluxes proper upon ores. Such metallic fluxes have generally sufficient affinity for oxygen to combine with or reduce the dissolved oxides in the molten alloy, and the chemical reaction liberates gases, which either raise the temperature by a definite amount of sensible heat, or lower the melting temperature of the alloy. Homogeneous metals result and in many cases the physical properties of the alloys are improved in a degree not otherwise obtainable.

So long as scrap metals are a part of the mixture, and there is no other practical way of using them, fluxes, whether metallic or neutral, must find a place in foundry practice, to act as cleansers or as aids to the closer union of the components. Very few of the alloys can be melted without decomposition, and no metal is exactly the same physically after it has undergone heat treatment. Fluxes are therefore essential to modify the defects of every-day melting practice and of all the fluxes in use the metallic preparations are the most convenient, only they must be used with moderation and in their proper spheres of influence.

Use of metalloids as fluxes.—The metalloids are best adapted for use in conjunction with the following metals and alloys:

Phosphorus in copper, tin, lead and aluminum.
Silicon in copper, copper alloys and cast iron.
Arsenic in lead, anti-friction alloys and copper alloys.
Manganese is highly beneficial in all copper-zinc alloys, nickel alloys and aluminum alloys.
Phosphor-tin, about 0.5 per cent, added to the white anti-friction bronzes, will prevent deterioration of the alloy in the heat.

Copper castings of high electrical efficiency.—Many experiments have been made in order to obtain homogeneous copper castings with a high electrical efficiency. It is highly important that the conductivity shall be retained as near to that of pure copper as possible, and the metal that is highest in this respect will be most in demand, for such castings as are required for electrical machinery.

One of the most successful is gained by using Cowles' silicon, aluminum and copper alloy (pulverized) and manganese dioxide mixed in equal quantities. To two ounces of this, add an equal quantity of a flux composed of borax and nitre equal parts; this is sufficient to refine 100 pounds of copper, and is added five minutes before pouring. A high degree of conductivity is claimed for this metal.

The following mixture for improving alloys was also the subject of a patent: Iron peroxide 33 parts, manganese peroxide 1 part, magnesium carbonate ½ part, aluminum 18 parts, silicon 3½ parts, sodium-biborate 4 parts. Phosphorus and aluminum both act as reducing agents in combination with other metals, and they are especially active in lowering the fusion-point of metals.

The addition of a flux is always advantageous. It cleans the metal, keeps it more fluid in the ladle, tends to set free occluded gases, and avoids blow-holes in the casting. Some of the so-called metallic fluxes have additional advantages, as aluminum in steel and iron, producing metal of superior ductility, toughness and softer skin for machining purposes, and taking away the tendency to chill at the edges or thinner parts of the castings; or bismuth in anti-friction alloys in reducing friction; or manganese in copper, making it possible to cast this difficult metal satisfactorily.

Flux for welding copper.—Boracic acid two parts, phosphate of soda one part; mix. Heat the copper pieces in a flame or gas jet, where they will not touch charcoal or solid carbon; strew the powder over the surfaces at a red heat, continue heating to welding point, then hammer.

Corrosion of metals.—Metals and mortals have their peculiarities and they possess many qualities in common. Both can be classified according to their affinities, grouped into families according to their characteristics, or ranged in line according to color. They have similar attributes, as hardness, conductivity, luster, etc., they are equally susceptible to treatment, and they are subject to many insidious diseases. Up to the present, however, only a few of the metallic diseases have been diagnosed. Metallic pathology—to coin a phrase and continue the analogy—is still in the chrysalis stage; it is a modern study about which only the most meager, scrappy information is available. The fact that familiar, every-day terms are still employed to denote or describe the diseases of metals, as *fatigue, rust, corrosion,* proves the traditional conception of the subject to be uppermost. In engineering circles there is no more hackneyed subject than the corrosion of metals; it would be difficult, therefore, for me to say anything new thereon. My aim, at present, is to bring under review the relative position of the more useful metals and alloys to corrosion; to consider preventives and to describe some experiences I have had with the plague in the practice of my ordinary vocation—brass founding.

Corrosion (Latin, *cor*—intensive, *rosus*—to gnaw) may briefly be described as the decomposition of metals by the agency of galvanic or chemical action. In the nature of things corrosion is a problem for electricians, but, while it may be necessary for me to refer to some general principles, I hope by relying on well-known authorities to avoid discussion on electro-technics. And here let it be emphasized that corrosion must not be confounded with another very common affection of metals, namely, oxidation. Oxide or rust may form on the surface of a metal and do it little injury, as, for instance, when zinc is exposed to air and moisture a gray film of sub-oxide is formed, which preserves the metal from further oxidation, or when monumental bronzes acquire the desirable *patina,* or colorations due to the production of cuprous-oxide in certain molecular conditions and the beauty of contour or ornamentation is enhanced. Corrosion acts differently. Most of the useful metals have some affinity for oxygen, and are therefore subject to oxidation, but *all* metals are conductors of electricity and they are therefore liable to corrosion under certain well-known conditions.

Contact theory.—The cause of corrosion is popularly explained by the theory of the galvanic current. Two metals in contact with the presence of moisture form a galvanic couple, and the difference of the force of attraction each metal possesses for electricity causes a current which has been called the electromotive force. Electricity is of two kinds, positive and negative, and it has been found that whatever metals are brought into contact with other, they show, when separated, opposite electrification. The following example will show how the two electricities may be separated from each other by the differing forces of attraction of different metals: Let us assume that negative electricity is attracted more strongly by copper and positive electricity more strongly by zinc. As long as the two metals do not touch each other the force of attraction is not called upon to act, as the two electricities are equally distributed over the plates. As soon as the metals touch each other, however, equilibrium between the electricities will be disturbed. At the place of contact two different forces are called into action, viz., the force of attraction between the two opposite electricities, and the different forces of attraction of the two metals; and electrical equilibrium is only possible when the resultants of these two forces are equal to each other. That is the *contact theory* briefly stated.

Chemical theory.—Let us now consider the *chemical theory*. When Volta, who was the first to observe that combination of two liquids and a metal produced a galvanic current, made his discovery, it was also found that greater quantities of electricity are generated by the contact of metals and fluids. This is due to the chemical energy of the elements, the liquids being decomposed by the electrical current. Numerous experiments have shown that all metals become negatively electrified when in contact with alkaline liquids; but in contact with acids, different metals behave differently. In the simplest form of galvanic battery where zinc and copper plates are immersed in a solution of sulphuric acid, the chemical process is as follows: Zinc in the presence of sulphuric acid decomposes water into its elements, hydrogen and oxygen. The zinc combines with the oxygen to form zinc oxide, which unites with the sulphuric acid to form zinc sulphate, while hydrogen gas escapes at the surface of the copper plate. Negative electricity is produced at the surface of the zinc plate and positive electricity at the copper plate, the potential of copper being higher than that of zinc. It is evident that under different conditions the same metals are sometimes electro-positive and sometimes electro-negative to each other, and as Prof. Sylvanus Thomson states, "If a metal tends to dissolve into a liquid there will be an electro-motive force acting from the metal towards the liquid and vice versa."

Galvanic theory.—The theory of galvanic action, in so far as it relates to metals, may be summed up thus: A current of electricity may be generated by two different metals in contact, by two different metals in the presence of a liquid, or by a combination of two liquids and a metal. Some metals have the property of being positively electrified in contact with other metals, or when submerged in a liquid, while others in similar circumstances are negatively electrified, but the polarity of the metals can only be known by experimental electricity or by a comparison of the relative resistances of the elements. The mechanical effect of this motion of the electricities, or current, is the separation of the elements, due to their chemical energy and the difference of electrical potential.

Let us now consider the practical aspect of the subject. Metals are popularly supposed to be stable bodies. Alas, they perish; they oxidize; they corrode; the unseen, in the form of gas or electricity, attacks them, and they crumble into powder. The universe is a gigantic laboratory for testing materials. From the recesses of her alchemical storehouse Nature can furnish unlimited re-agents to precipitate the last of the elements. No wonder chemists and philosophers tell us "nothing is permanent but change." Attempts have been made to counteract the effects of corrosion, in some cases by neutralizing the electrical potentialities of the metal, and in others by re-establishing electrical equilibrium.

In consequence of the rapid deterioration of iron and steel, hydraulic and mining machine parts and sanitary appliances are preferably made from some material less liable to corrosion. It is unfortunate that iron, the cheapest and most useful and important of all the metals, loses more of its vitality from this cause than any of its rivals. Alloying is said to retard corrosion. Cast iron alloys containing copper and lead have been tried, but with indifferent success; nickel steel stands no better than the ordinary kinds. Certain chemical alloys, as Parsons Manganese bronze and Dick's Delta metal, are said to be immune, but it has been found that while they may show little signs of corrosion themselves, they afford no protection to other metals like iron or steel. This is proved in the case of ship's propellers. Zinc plates and linings are just as necessary to prevent corrosion of the hull and aperture when these alloys are used for casting propellers as when the common brass or gun metals are employed.

Since the introduction of the electric light on board ship there has been a noticeable increase in the number of broken tail-shafts, pitted liners and corroded apertures. The importance of securing perfect electrical contact in making connections is of more moment on board ship than anywhere else. The loss of a tail-shaft or the bursting of a condenser tube from corrosion may mean a serious loss of life. It is the general practice to interpose some inert, non-corrosive substance between metal and liquid bodies to preserve the former from the destructive influence of corrosion. Thus it is customary to preserve the hulls of ships, or constructural iron work of any kind, by a coat of paint, and tinning is a favorite remedy for preserving metals liable to corrosion, but these things only afford temporary protection. There are so many perplexing causes of corrosion that it would be impossible to find a universal remedy. Ships are liable to be attacked inside as well as outside. Oxidation of sulphur from coal, the presence of metals electro-positive to iron and steel, the existence of moist air in the holds, the possibility of a leakage of the electric current from the dynamo, and other similar agents are ever active. Nickel appears to be less readily corroded than most of the other metals. Prof. Ernest Cohen, Amsterdam, recommends nickel drawn tubes for condensers, and he specifies oxide of copper and nickel as being proof against the corrosive action of sea water and atmospheric air.

An instance came under my notice lately, proving that nickel-plated table ware was superior to silver-plating for wear and liability to corrosion. A new mail steamer was furnished with a fine display of E. P. silverware, but some months afterward a greenish, speckled coating began to appear on the surface. The articles were ordered to be replated, this time with nickel, because it was cheaper, and since then they have been giving satisfaction.

Much could be written about the relative merits of the various metals and alloys as anti-corrosive substances. Dr. Richards says: "Pure aluminum resists corrosion better than almost any of its alloys." The same might be said of every other metal. Impurities accelerate the corrosion of metals, and it is worthy of mention that the laminations in wrought iron plates, or the spongy places in a casting, are more readily corroded than the homogeneous metal. But oftentimes the casting is blamed for the trouble when some other thing is the cause. Owing to the sulphur used in its preparation, the rubber insertion used in packing valve faces is a fruitful source of corrosion in cast iron steam chests, etc. Pure rubber is costly and the commercial article is loaded with adulterants, especially sulphur. When the corrosion is discovered the engineer whines, "We don't get castings like we did 10 or 12 years ago." The fact is engineers are getting better castings, but poorer supplies, with the usual unsatisfactory results. Corrosion is a disease with complications, and the personal equation counts for a great deal in the combat.

The diseases of metals may be summed up into three distinct classes, according to the nature of the causes which produce them: First, diseases of treatment, embracing metals which have been rendered weak by thermal or mechanical treatment; second, diseases of composition, arising from the presence of bodies foreign to the metal or alloy; third, diseases of decay, arising from the action of outside causes, either chemical or mechanical, on the metal, and leading to deterioration.

XIII

GATES AND RISERS FOR ALLOYS

THE gating of castings reflects the individuality of the tradesman more than any other single operation connected with the art of molding. Why?—Because the gate is the only part of the mold which is made independently. Except in the case of machine-made or repetition molds, no indication of the duty or design of the gates necessary to run the castings ever appears on the pattern. The molder must think this out for himself and as often as he gets a new pattern to work from, the problem of gates and risers presents itself. In the production of castings the making of the mold is not everything, the gating is not less important than the ramming, the venting or the binding. Every different class of work requires separate consideration. In ornamental castings the gate must not interfere with the design; for light castings it must be cut to fill the mold uniformly; for heavy castings it should be constructed to avoid wear or scabbing and to feed the parts solidifying last.

Again, the gate which would be ample and successful for a casting in cast iron would many times bring disappointment if used on a similar casting in gun metal and would certainly fail with cast steel. Whatever metal may be used, the fluid characteristics of the metal and its behavior on solidifying, want careful study in order to avoid undue shrinkage, draws, cold shuts, scabs, scale, etc. With alloys this is especially true. They are fickle compounds, and more sensitive to variations of temperature and conditions than the homely cast iron. The primary object of a gate is to fill the mold with clean metal and in cutting the gate, the molder naturally selects the line of least resistance for the flow of the metal, unless some other consideration, as machining, or avoiding the use of chaplets, is taken into account. Fig. 16 is a simple illustration of how not to gate a casting. Here we have a spray of washers with square holes. The gates are so led that the metal in passing through the mold, must wear away the sharp corners and the castings will contain minute specks of sand, making them unsightly and difficult to polish. Fig. 17 shows the remedy for this. Fig. 18 is a section of a 4-inch brazing metal bend for distillery coils. These castings are only 5-32 inch thick.

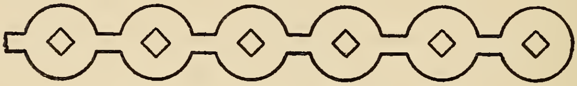

Fig. 16—Improper method of gating

Fig. 17—Proper method of gating

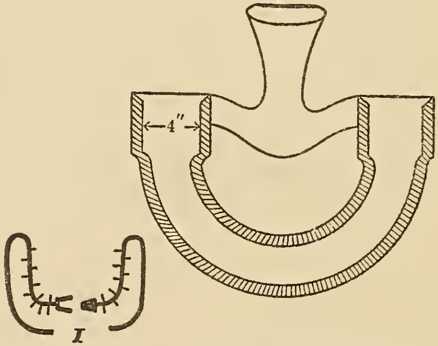

Fig. 18—Section of a 4-inch brazing metal bend

They are made from a shell pattern with green sand core. The core iron, made of ⅝-inch square iron, comes in two halves as shown at *I*. No chaplets or nails are used; the core iron is rigid when closed and the legs are long enough to balance the core. A pressure of 36 pounds per square inch is applied to the castings and the best results follow from the method of gating shown. Fig. 19 is another example of a light casting, a cover for an electric drill motor. The gate shown is for yellow brass, but sometimes these are cast in aluminum, when a different method is adopted, as shown in Fig. 20. This illustrates the fact that gates should vary with the metals used as well as with the forms of the castings made. The disposition and dimensions of gates and risers is not a subject about which one may dogmatize or lay down hard and fast rules. Similar castings may be successfully run by different gates. Take the blank gear wheel, Figs. 24 and 25. Five different gates are shown, any one

Fig. 19—Method of gating a cover for an electric drill

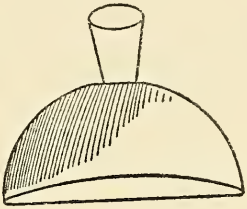

Fig. 20—Method of gating when cover is cast in aluminum

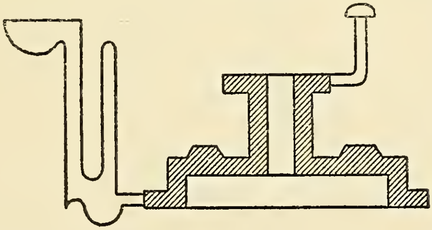

Fig. 21—Skimming gate to insure clean metal

of which may be adopted with success if attention is given to the casting temperature (gun metal is meant) and the condition of the mold. The question of machining often decides the method of pouring. A casting which has to be machined all over is generally cast vertically, or with the smallest area at the top. Fig. 24 fulfills the latter condition better than any of the styles seen in Fig. 25, but it is open to objection on account of the gate being placed on the most critical part of the casting, that is, where the teeth are to be cut. The easiest way to make a mold is not always the best for the casting; much depends on where the important parts are located. Usually, particular parts or machined surfaces are made to form the under side of the casting as the top side, in horizontal pouring, is always weakest. Fig. 26 shows the general practice in marine brass foundries in casting valve seats. The mold is made with the flange uppermost and when it is finished it is turned over and what was the drag in molding becomes the cope in casting. The tiniest speck on the face of this casting would condemn it. Engine brasses supply another example of the same practice. Fig. 27 illustrates one style of gate and Fig. 28 is an alternative gate used with such castings as are molded in three-part flasks. The whole of the

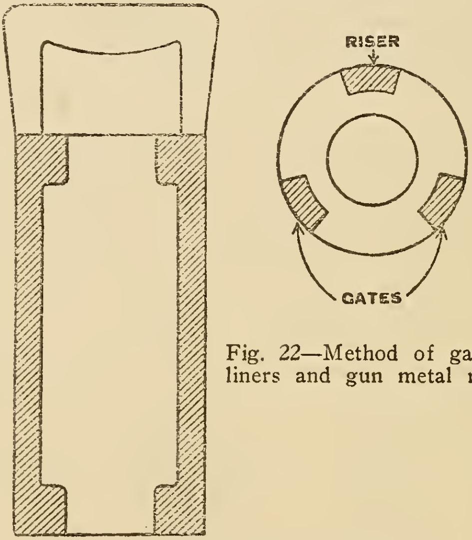

Fig. 22—Method of gating liners and gun metal rolls

gate, Fig. 28, is cut in the cope, except the small leaders represented by dotted lines in Fig. 27.

Casting brass on iron.—The most troublesome job that falls to the lot of the brass founder is to cover a rod of iron, say a pump rod or a shaft, with a liner of gun metal, Fig. 29. To cast a liner on a shaft is a simple enough matter in itself; but to obtain it free from blow-holes, cracks or strains is the difficulty with which the brass founder must contend.

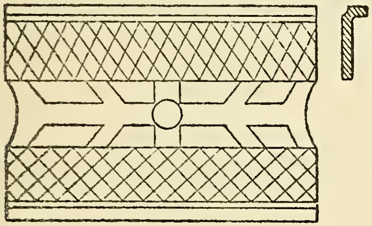
Fig. 23—Method of gating a stair tread

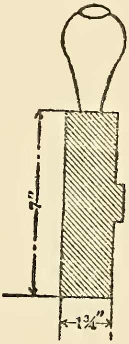

Fig. 24—One way of gating a blank gear

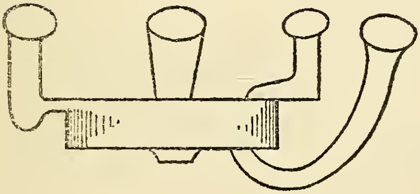
Fig. 25—Four different methods of gating a blank gear

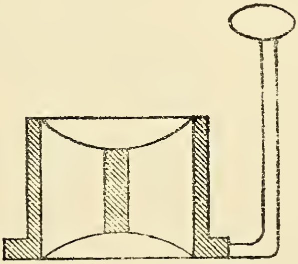
Fig. 26—Usual method of casting valve seats

Casting brass onto iron or steel is always a difficult matter to accomplish satisfactorily. The expansion of the metals is different, causing cracks; the affinity of the metals is weak, the iron repelling the brass and creating sponginess; besides it is well known that iron, when it is heated, emits a gas, which in the case of shaft liners accumulates inside the mold when it is closed and is absorbed by the molten brass when it is poured, producing troublesome blow-holes. The remedies for these evils are first, not to overheat the iron, a very dull red scarcely perceptible in the shade being all that is required; second, to provide sufficient risers for carrying off the gases and feeding the casting. Pump rods, feed screws, eccentrics, and other small gear, are usually lined in vertically cast molds, but with tail shafts running 12 feet and upwards in length, and weighing several tons, this method is impossible. Horizontal pouring may be quite as successful if the precautions already indicated are taken. From Fig. 29 it will be seen that a bed plate is leveled to receive the shaft which is supported by iron stools having V-shaped notches on the top. Strips of wood the required thickness of the liners are then tied around the circumference to form the patterns and the molds are rammed up with the shafts in position, the parting being formed at the center. The copes are then removed and the shaft lifted out and placed on supports ready for heating. Great care is necessary in this part of the work as the shaft is liable to warp if it is not properly blocked up. The number of risers strikes the

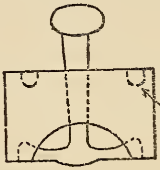

Fig. 27—One style of gate used for casting engine brasses

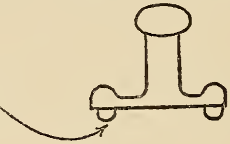

Fig. 28—Gate for a casting made in a three-part flask

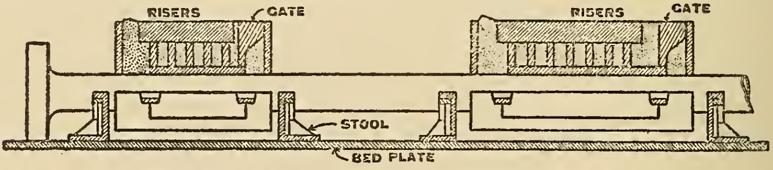

Fig. 29—Arrangement of mold for casting brass on iron

average molder as being abnormal, but these are exceptional castings and if an open, continuous riser could be arranged for, instead of a series at short intervals, the results would be even better. Risers are chiefly used to relieve the pressure on the mold, to prevent gas cushions, to collect dirt, to keep open communication with the mold as a tell-tale during the cast and to feed heavy internal sections.

Risers are never used on large bells because the metal, to ring well, should be as dense as possible; this object can only be attained by giving the sounding rim all the pressure available. To prevent sullage or dirt entering the mold, what is termed a *plug head* is used. A dry sand runner basin is made up on top of the mold and a plug made to fit the down-gate by casting a section from the gate pin in plaster of Paris and inserting a hooked iron therein before the mixture sets. This plug is fixed in the gate, while the head is filled with metal. It is then lifted out by using a rod of iron as a lever and the ladle keeps a constant level of metal in the head until the mold is filled up. The plug head is largely used for statuary and heavy ornamental castings.

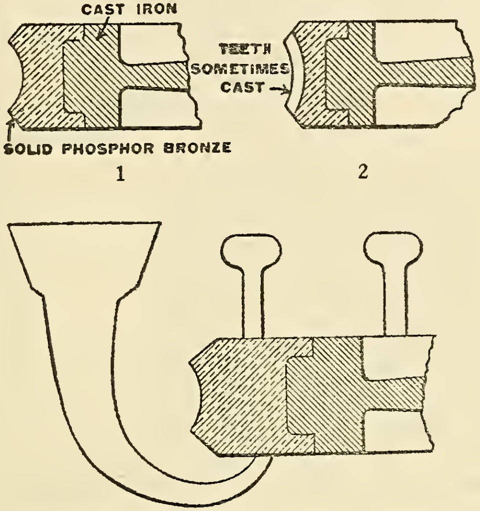

Fig. 30—Method of casting a pinion with a horn gate

Other forms of gates devised to admit only clean metal to the mold are skimming gates, Fig. 21 and core gates, Figs. 31 and 32. We have seen then, that the gate varies with the style of casting and with the nature of the metal. For thin, light yellow brass castings as stair treads, Fig. 23, the gates should be shallow and wide, with a heavy down-runner to make it easy to fill the mold quickly. Another fine example in this class, but of a more ornamental nature, is shown in Fig. 34. This is the reproduction of a match-plate for a casting made by the National Cash Register Co. Such castings require skill in pouring the metal; indeed in foundries where much light work is made the pouring is done by a class of men called *casters*. These men are expert in filling such molds, and wasters due to irregularities in pouring are reduced to a minimum. It may be mentioned here that we have intentionally avoided any reference to the fixing of gates on machine-made molds. That is a special branch of the subject which would be better dealt with by an expert in machine molding. Great ingenuity is often displayed in arranging the patterns for an odd-side, or for spray work in plate molding or machine-molding. The main object is to press as many pieces as possible within the area of the flask, in positions that will give good, clean castings, with gates which will be economical of metal in casting and also of labor in cleaning.

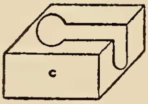

Fig. 31—One style of core gate

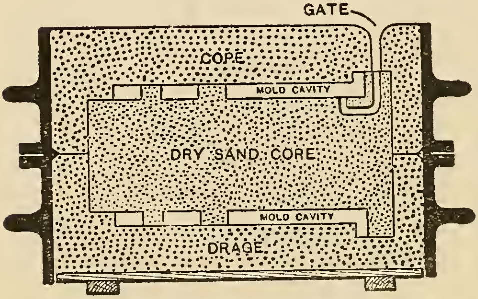

Fig. 32—Cross-section of mold showing the use of a core gate

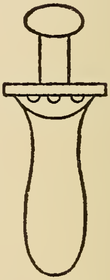

Fig. 33—Casting a propeller blade in a vertical position

How to gate castings.—A few pointers on gating follow:

The flow of metal should not meet with any obstruction on entering the mold.

As a rule, the mold should be gated at a heavy part.

The smallest sprue, which will run the casting satisfactorily, is the best for overcoming faults in pouring.

The drop gate is very useful for thin castings of large area as well as for heavy castings with variable thicknesses.

In some cases a cleaner and sounder casting can be obtained, when the metal enters at or near the bottom.

Round gate pins give the best results generally.

Spray gates should make a short connection with the leader and they should always be deeper and wider there than at the mold cavity.

The pouring basin or head should be so constructed that it can be kept full, otherwise the dirt, which collects on the surface of the metal, will be washed into the mold and result in a defective casting.

Core gates are useful when it is desirable to fill the mold with a gentle stream from the interior.

On intricate castings the gates must be distributed to insure that the metal shall reach the vital parts in good condition; at the same time care must be taken to avoid scabs from the metals impinging upon weak internal parts.

In gating phosphor bronze castings, molded in green sand, make a practice of feeding the heavier parts through the nearest lighter section.

Don't experiment with a new gate if the one regularly in use gives satisfaction, unless it is to economize metal or facilitate molding.

Heavy castings call for good judgment to decide upon the size and number of gates required.

Alloys high in zinc, as manganese bronze or Muntz metal, should have heavy plug heads for heavy work. The plug head, which is simply a dry sand head with a plug fitted in the runner, is also used for casting statues made by the *cire perdu* process.

In making up the head for a large mold the runner basin should be central, if possible, so as to give an equal distribution of the metal to the gates. Making up the head is a part of the work, which is apt to be hurriedly done, since it is the last duty in preparing the mold for casting. Carelessness in this part of the work will spoil the casting just as readily as bad molding. The gates illustrated, are only a few selected for their interest to general brass founders.

Firms adopting a specialty soon find out the most practical means of gating the castings they make. For example, screw propeller blades for ships are recommended to be cast in manganese or aluminum bronze. It was found that the horizontal method of pouring such castings in gun metal gave unsatisfactory results with the alloys mentioned. Now, propeller blades in manganese and other bronzes are invariably cast in the vertical position, Fig. 33. This is an ideal style of casting for pouring on end because it is self-feeding and in cooling out it sets from the bottom upwards. Nevertheless, horizontal pouring is necessary when gun metal is used. The liquidation of the tin in heavy masses of gun metal, would produce a casting with brittle edges and irregular composition in the thicker parts of the blade if it were cast vertically.

Fig. 35 shows the gate on a church bell; Fig. 22 shows the method of gating liners and gun metal rolls; Fig. 30 shows the use of the horn gate; the illustration is a cross-section of a pinion wheel for heavy gears and they would probably weigh from 60 to 100 pounds. Dry sand molds are essential for this class of work. The ordinary method of avoiding air holes in such castings is to flow a surplus of metal through the mold. It is believed that the gases rising from the heated iron are, by this means, carried away from the casting. With a sluggish fluid like gun metal, this flushing of the mold is good practice, but with a highly fluid metal like phosphor bronze it would be positive extravagance. For this casting I would recommend a good, old-fashioned horn gate; for the larger sizes two gates at opposite points, to be poured with two crucibles, with risers distributed on the cope at regular intervals, say six inches apart all around the circumference. Fig. 30 also shows a cross-section of the rim of a

Fig. 34—Match-plate for a brass, cash register casting

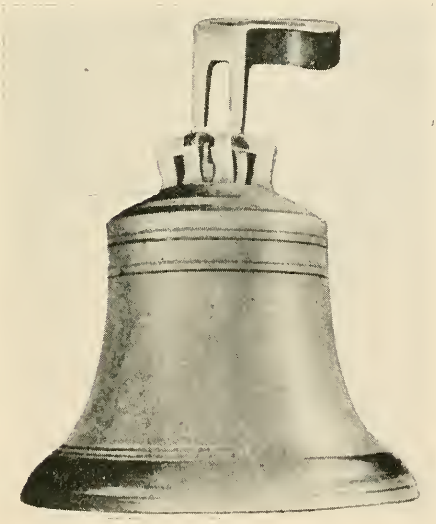

Fig. 35—Method of gating a church bell

gear with a horn gate and risers; 1 shows a cross-section of the gear when cast blank and 2 when cast with the teeth in it.

The cast iron center should be of close-grained iron and it would be a decided advantage to have it twice heated before being placed in the mold for casting. Perhaps the most important consideration in such castings is the temperature. The iron should not be raised above a dark cherry hue when first heated. At the time of casting, a dark red heat should be sufficient.

As regards the casting temperature of alloys, we have still to depend upon rule-of-thumb. I would not advocate hot metal for this job as some do, because the hotter the metal is made, the more active it is to form and absorb gases. The blow-holes complained of are common to all the conditions of casting copper alloys upon iron and it is always possible to minimize them by conducting the gases freely from the mold.

XIV

ABOUT CRUCIBLES

THERE is a book entitled, "Crucibles, Their Care and Use," published by the Joseph Dixon Crucible Co., Jersey City, N. J., which should be in the hands of every crucible user and every melter of alloys. The purpose of this book is to inform the user of crucibles as to their nature and characteristics, and to give him suggestions as to their care and handling, which, if followed, will add to their efficiency and greatly prolong their usefulness.

We must concede that the makers should have learned by this time about all there is to know of the use and abuse of crucibles. The graphite crucible is the last word on melting pots. For mixing all sorts of alloys it is an ideal vessel; refractory, flexible, capable of withstanding sudden changes of temperature and strong enough to be handled with freedom, but not with impunity as some people imagine. If you are going to get the *best* out of anything, you must give it your respect. The plumbago crucible is like this, and nearly all of the troubles complained about are due to the absence of the last named attention.

In my experience, crucibles are like men, if you treat them properly you get a fair return. The average life of the crucible depends greatly upon the conditions under which they are worked. The crucible, which is used in one of the modern tilting furnaces, may give 100 per cent more heats than the one used in a pit furnace with a blast connected. A good general average of heats for the various metals melted in a natural draught coke or coal-fired furnace would be for brass, 40 heats; for gun metal, 35 heats; for copper, 22 heats; for German silver, 18 heats; for malleable iron, 16 heats; for steel, 7 heats and for nickel, 4 heats.

These figures, however, just as they are beyond the attainments of some people, would not satisfy the requirements of other and more expert melters who are capable of a melting ratio far more favorable to the use—and by the same token to the maker—of the crucible.

Causes of premature failure are annealing on the top of the furnace, bad fitting tongs, improper charging of the metals, ramming of the fuel, soaking and rough usage.

Figs. 36, 37, 38 and 39 amply illustrate the troubles to which crucibles are prone. The scalped crucible, Fig. 36, is a sight to make the gods weep. The potter's vessel dashed in pieces by gross carelessness. Let the manufacturer explain, if he can. And he does in this way: "When the crucible comes from the kiln it contains less than one-quarter of one per cent combined moisture. In this connection it is absolutely impossible to scalp it, but the moment it cools off it begins to absorb moisture from the air, and once absorbed it requires a temperature of not less than 250 degrees Fahr. to dispel this moisture. It is also essential that the crucible be kept to this temperature to prevent its absorbing the moisture again."

So simple! And yet many profess to be astonished when disaster follows neglect. For the proper annealing of crucibles four rules should be observed:

First—The temperature must go above 250 degrees Fahr.

Second—This temperature should be reached gradually.

Third—This temperature must be held long enough to expel the moisture in the crucible. Ten hours is given as an approximate time for a No. 200 crucible.

Fourth—The crucible must go in the melting furnace with a temperature above 250 degrees Fahr.

After the crucible has been successfully annealed, some melters breath freely and concern themselves no more about it. Now, the crux of the question of crucible longevity lies in giving proper treatment and care to the pots from the time of delivery to the time of doubt, that is, when it reached the condition shown in Fig. 37, and deserves honorable mention for long and faithful service. Alligator cracks is another serious defect, due to hot gases and improper annealing. It matters not if you use oil or solid fuel, all fuels culminate in gas and the products of combustion. The moisture in the hot gases condenses on the wall of the crucible, an oxidizing condition develops and alligator cracks are the result.

Pin holes, Fig. 38, are a more subtle defect. They develop after the crucible has been in use for some time, and it is not so easy to apportion the blame for their appearance. The manufacturers admit the possibility of an occasional bad pot, but most practical men will appreciate the wide margin which exists between the number of heats obtained by a careful and skillful melter and one who does not bring the same care and intelligence to bear upon his work. Pin holes are probably small fissures developed either during the drying or the annealing of a crucible, and the personal equation seems to enter largely into the disorder.

The squeezed crucible, Fig. 39, bears witness to the kind of tool in use and the kind of men who use them.

Two things about crucible economy loom up with impressive persistence and vigor: First, moisture is the greatest enemy to the life of a crucible, and second, prolonged melting and intermittent heats are responsible for most of the poor averages in ordinary foundry practice.

It is just as well to remember that the enemy in the form of moist, hot gases due to imperfect combustion, say when you are holding back the metal to suit the molder, may be getting in some deadly work unknown to you, except by a low average of heats from the crucible. And you can hardly put a bigger strain upon a pot than to leave it out in the open overnight and charge it cold into a fresh fire in the morning.

As regards the shape and capacity of crucibles, the most popular shape for alloys is the wide-mouthed Scotch pattern. For steel and metals requiring high temperatures, the barrel or olive shape is favored. The actual capacity of the different styles varies with the nature of the metals melted. Crucibles for brass are made in England to hold one pound of molten metal per size unit, and a No. 20 pot will hold 20 pounds of metal. The Scotch shape is proportioned to hold two pounds per number,

Fig. 36—A scalped crucible

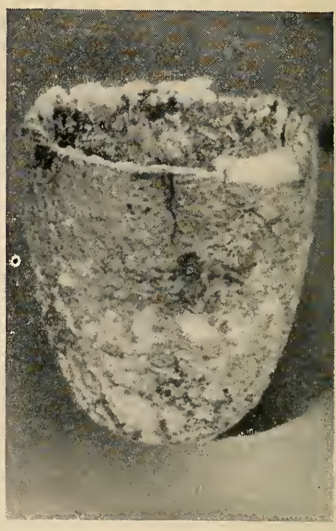

Fig. 37—Crucible showing the cracks which begin to form at the top when its life is nearly ended

Fig. 38—Crucible showing pin-holes from which metal has leaked

Fig. 39—Crucible squeezed out of shape by tongs

Illustrations from "Crucibles, their care and use," published by the Joseph Dixon Crucible Co., Jersey City, N. J.

and American shapes have capacities up to three pounds of metal per size number. As the capacity of a crucible is sometimes limited to the amount of light or bulky scrap which it can contain in unmelted form, the reason for favoring a wide-mouthed shape for alloys will be quite obvious.

The question is often asked "Who makes the best crucibles?" The answer to that is contained in the answer to another question, "Who takes the best care of his crucibles?"

Some uses for old crucibles.—Plumbago crucibles are an important item in brass and steel foundry expenditure, but as the expense is a necessary one, it behooves the practical tradesman to be careful how he uses them. I can answer for my own method as being both safe and economical. Our standard number of heats for melting brass in crucibles is 34. I fancy I hear a snicker go round at the modesty of the figures. Someone is sure to exclaim: "Oh! we can get 40 heats on an average and we have had '50 not out' on more than one occasion." I believe that, because I too have had the same pleasure. When I say that the standard number of heats with us is 34, I mean to imply that we look upon that number as the minimum we should get with ordinary usage. We melt 17 heats per week from each furnace, and every crucible we put in is expected to wear for a fortnight; but under no circumstances do we use one for a longer period than 3 weeks. When we have had the use of a crucible for a fortnight continuously, we reckon it has paid for itself, and, if at the end of the third week it is still sound, as often happens, the chances of its giving out within the next day or two are too great to make it worth while risking the loss, danger and annoyance which always accompanies a *burst,* either in the furnace, or out of it.

Many furnacemen make a practice of sweating the pots by putting them, mouth downwards, back into the furnace every night after the last heat, ostensibly to keep them clean. I find they can be kept clean much easier and with less wear, by paying attention to the inside wall when skimming the dross off the metal, or at the finish of each heat. When the last heat for the day has been cast, it is always better to empty the crucible and turn it upside down behind the furnace it was taken out of, leaving the back half of the furnace uncovered. This allows the crucible to cool out gradually and avoids much of that cracking noise you hear when it is cooled in a draught.

A new crucible should not require sweating before the twelfth or fifteenth heat and about every ninth heat thereafter, but much will depend on the nature and condition of the metals to be melted. With clean ingot metal it is easier to have clean crucibles and increase the average number of meltings.

The man who gives his pots a nightly sweat gets them thin and fragile in a much shorter period than the non-sweater. That means his crucibles are more liable to squeeze, split or collapse.

The other extreme is reached by the lazy villain who never sweats the pots at all, but leaves the spare metal to set in their bottoms and wonders why so many pots run with the first charge in the morning. If, through inadvertence, you should at any time have metal set over night in the bottom of a crucible, take my advice and dump it out before you recharge it. Put some borings or other metal in the bottom before placing the nugget back in the crucible; you can then proceed to melt the metal with confidence.

I have come to the conclusion that much sweating saps the life of the pot, just as it would the potter were he amenable to the process, and the sweating system is good for neither pots nor people.

The career of a crucible is oftentimes an instructive lesson. When it has rendered good service and worn itself out as a melting pot it may still be utilized for many purposes undreamt of by the makers. One has only to look around one of the jobbing foundries to realize this. There you may see the crippled-crucible-swap-pot, or the plumbago parting sand dish, and if you happen to know in which suburb the manager lives you may tell his house by the sable flower pots in the side passage. There is no great novelty in any of these adaptations and it requires no inventive ferment of the average brain to discover many similar uses for faithful old crucibles. The genius, being differently constituted, intuitively finds an entirely new use for any old thing; he cuts and carves it to his liking. Witness that original idea for a self-skimming ladle. The recipe is as follows: Cut an old crucible in halves longitudinally; when daubing the ladle fix one of the pieces inside near the pouring lip, to form a pocket or division. Another good idea is to cut the bowl of one of the larger sized pots, say 5 inches from the bottom, invert, and place on the fire-bars of the furnace, to be used as a stand for the melting pot to sit upon. This arrangement saves fuel and has the advantage of keeping the crucible always at the same height in the furnace. In the same way old bottoms make handy crucible covers for melting steel, or German silver alloys. I do not pretend to know all the ways in which worn out crucibles can be used; I have seen them used as annealing pots; also for burning parting sand in; and when the sight of them has become tiresome, a last charge of skimmings or washings would be packed into one of them and melted over night. In the morning the staunch old friend would get his death blow; the button of metal would be put on one side, while the remains—well, I shall have more to say about the remains further on.

Economy is a virtue and I want to instil it by showing that dilapidated crucibles may be put to some more profitable use than the decoration of the foundry dump or truck heap. Even if they are beyond any of the uses already mentioned, they may be ground and mixed in many ways with obvious advantage. In some localities hawkers buy up broken crucibles for a few cents per hundred weight; and resell them to the facing mills. It struck me as peculiar that the material in a graphite crucible should realize so little when it was done with for melting purposes, especially when it is taken into consideration that the heat treatment it receives makes no appreciable difference on the incombustible ingredients. When you cut off the glaze from the outside of an old crucible there is practically no difference in the body of the material; besides if it pays a hawker to collect and resell them to the grinders, why should it not be profitable for the foundryman to grind them himself? Every foundry of any size has a mill and some hair sieves. Let us see what can be made of the stuff anyhow! "Pugging" is a trade name for the soft fire clay, cement or mortar used for repairing chimneys, furnaces, etc. The best pugging I know of is ground crucibles mixed with clay wash. The ordinary sand daubing is vastly improved by the addition of a shovel full of ground crucibles. Pure plumbago facing does not adhere well to the surface of green sand molds but mixed with ground crucibles and talc up to 20 per cent it may be relied upon. Ground crucibles mixed with oil makes a splendid substance for stamping branch cores, or for getting a bearing by making up the space between core and print, or core and core, as the case may be. Steel founders use fire clay in some of their facing sand mixtures but ground crucibles is a good substitute; it also makes a good mixer for core sands, in brass foundries, wherever the ordinary mixtures are liable to burn or fuse. Moisture in a crucible before it undergoes annealing generally results in its being scalped; but when once it has been thoroughly annealed there is not the same risk, if a little moisture gets on the outside of it.

My reason for making this statement will be explained by what follows: Many years ago I received my first appointment as a foreman brass molder; it was in Edinburgh, Scotland, and there were 14 crucible furnaces in the shop. The first morning I was perplexed to see the two furnacemen brushing the outside of the crucibles with a black looking slurry, before charging them. On the second morning the same maneuvers were gone through so I ventured to ask for an explanation. I was informed that this had been the practice ever since "Mr. James," came back from France,—some 14 months. The mixture consisted of fire clay and our old friend ground crucible, half and half, mixed with water. A new pot was put in for the first day *au naturel;* after that it got its morning coat of *black jack*. The result convinced me that "Mr. James" was no friend of the crucible manufacturer. His method added at least 30 per cent to the average life of a crucible.

To make a stirrer with *black jack,* put two strips of wood on a face board, as you would in making clay thicknesses. Let them be 1¾ inches apart and 1½ inches thick. Pack the space with the mixture, which is improved if moistened with liquid core gum instead of with water; insert a bar of 1¼x¾-inch iron, raggled for about 16 inches at one end. Slick-off the superfluous mixture, allow it to stiffen, unscrew one of the strips of wood and lift the affair into the stove. In the morning you have a home-made plumbago stirrer.

XV

TESTING ALLOYS

THE manufacture of testing machinery has been brought to such a high state of efficiency, that many firms making high class castings for which tests are essential, prefer to install one or two machines and perform all tests in their own workshops. Messrs. W. & I. Avery's testing machines are in use in some of the largest engineering laboratories in the world. They have a reputation for being sensitive, accurate and of sound construction.

Fig. 40 is an illustration of an improved, hydraulic, vertical testing machine, single lever type, for tensile, compressive and transverse tests, capacity up to 150 tons.

Fig. 41 is a novel impact testing machine which is self-registering, indicating the number of foot-pounds of energy absorbed by the specimen, which is fractured in one blow. The value of testing by impact has been fully demonstrated particularly when any material is required to withstand shock. Another feature of impact testing is that the fractures made show agreement with the micro-structures, and enable the expert to determine the relative contents of the specimen and its previous thermal treatment.

All physical tests are comparative, and it is a mistake to rely upon any single test for the capabilities of any material. With alloys, the tensile test is too often the only one. Different metals call for different tests and comparisons, and if a combination of two or more tests are conducted simultaneously on the same metal, a great deal more of its history can be ascertained, and better work may be done through the application of the knowledge thus gained.

Tests for various metals.—The recognized tests for cast iron are the transverse, tensile, compression, impact and shrinkage tests.

For gun metals the principal tests are tensile, torsion and impact.

For high tension bronzes the principal tests are bending, tensile, torsion and elasticity.

For anti-friction metals, the principal tests are compression, friction and hardness.

Whatever the nature of the test, some force is directed upon the material, and calculations based on the amount of work done, are made. This does not show the relation of the test piece to forces outside of the original test, hence the need for combining several tests in one sample of the alloy. All tensile tests should be accompanied by a statement of elongation and the reduction of area. The transverse test is chiefly used for cast iron. All friction tests should indicate the method of lubrication, if any.

Notes on test bars.—A few suggestions regarding test bars are given below:

It is usual to make two bars for every test.

Test pieces of large section give lower results comparatively than small sections.

Increase of density and strength generally follows an increase of static pressure in the mold.

As a rule, test bars should be cast in the vertical position.

Brass and nickel alloys should have a riser attached.

Owing to the tendency of tin to segregate, some gun metal —copper and tin—mixtures give better results when the bars are cast in the horizontal position.

When a test bar is specified to be cast on a casting, the best results are obtained when the bar is about the same sectional area as that part of the casting to which it is connected, and also when it is as far away from the main body of metal as

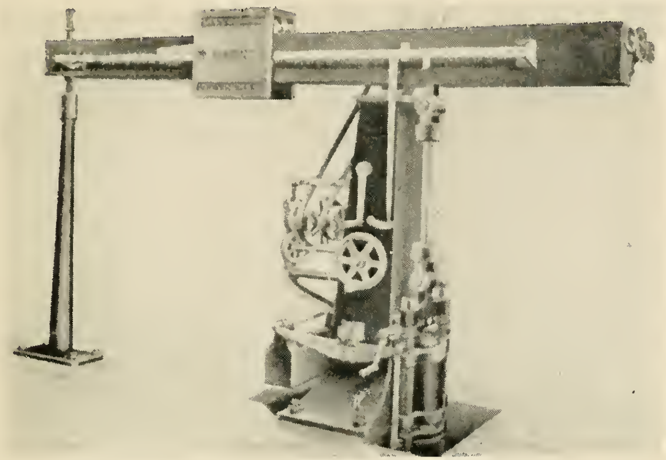

Fig. 40—Vertical, hydraulic testing machine

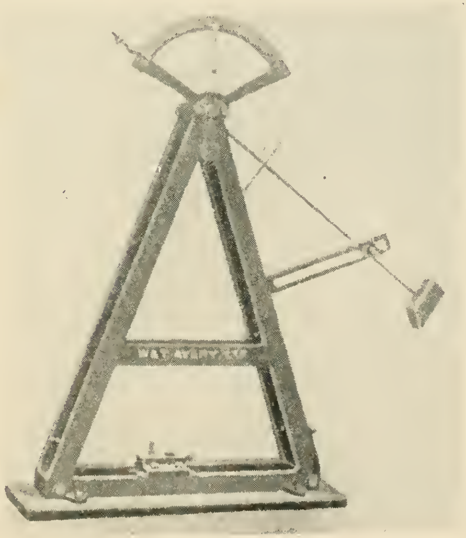

Fig. 41--Impact testing machine

possible. This insures a uniform cooling rate, and more truly indicates the character of the casting at that particular part.

Rounded corners and very gradual changes of section are advisable for all bars that have to undergo tensile, torsional or elasticity tests.

Test pieces should not be cast on the top part of a casting. They only act as risers, collecting dirt, and are likely to contain flaws.

The principal test should always be the one which most closely resembles the strains that the alloy will have to stand when in actual use.

All the variations in strains, pressures and speeds that castings are subject to in practical use, cannot be reproduced on a testing machine, but the physical tests taken in conjunction with the microscopical and chemical deductions, afford ample information for the safe amount of burden that may be imposed on the alloy.

The casting temperature of alloys is of greater importance than the rate of cooling, although both conditions exert a powerful influence on the physical properties of the castings. With cast iron, variations in the rate of cooling have more pronounced effects than variations in the casting temperature. With alloys, especially of copper, the casting temperature is of paramount importance.

PARTICULARS OF ALL THE KNOWN METALS

Metal	Symbol	Color	Atomicity, new system	Specific gravity	Specific heat at 0 Cent.	Electrical conductivity mercury at 0 Cent.	Heat conductivity silver =100
Aluminum	Al	Tin-white	.271	2.56	.2253	20.97	31.33
Antimony	Sb	Silver-white	120.43	6.697	.0523	2.05	4.03
Arsenic	As	Steel-grey	75.01	5.727	.083	2.679	
Barium	Ba	Ylwsh.-white	137.43	3.5-4			
Bismuth	Bi	White	208.11	9.759	.0305 at 20°	.8676	1.8
Cadmium	Cd	White, blue tinge	112.3	8.65-8.8	.0548	13.46	20.06
Cæsium	Cs	Silver-white	132.9	1.88			
Calcium	Ca	Ylwsh.-white	40	1.82	.1686	12.5	25.4
Cerium	Ce	Steel-grey	140	5.5	.04479		
Chromium	Cr	Greyish-white	52.45	6.8-7.3	.0998		
Cobalt	Co	Steel-grey	58.8	8.52-8.95	.107	9.685	17.2
Copper	Cu	Reddish-ylw.	63	8.36-8.95	.0933	52 to 54	73.6
Didymium	Di+Pr	White	142	6.544	.04563		
Erbium	Er		166				
Gallium	Ga	Silver-white	70	5.96	.079		
Germanium	Ge	Greyish-white	72.3	5.469	.0737		
Glucinum*	Be or Gl	Steel-colored	9.08	2.1	.4702		
Gold	Au	Yellow	196.5	19.3	.0316	43.84	53.2
Indium	In	Silver-white	113.4	7.4	.05695		
Iridium	Ir	Grey	192.5	22.38	.0323		
Iron	Fe	Greyish-white	56	6.95-8.2	.114	9.68	11.9
Lanthanum	La	White	138.5	6.163	.04485		
Lead	Pb	Blue-grey	206.4	11.4	.03065	4.8	8.5
Lithium	Li	Silver-white	7.03	0.578-0.589	.9408	10.69	
Magnesium	Mg	Silver-white	24.36	1.75	20°-51.245°	22.84	34.3
Manganese	Mn	White-grey	55.02	8	14°-97°		
Mercury	Hg	White	200	13.6	.033	.1	5.3
Molybdenum	Mo	Dull silver	96.	8.62	.0659		
Neodymium	Nd		143.6				
Nickel	Ni	White	58.7	8.3-8.7	.10916	7.374	
Niobium†	Nb	Steel-grey	94	4.06			
Osmium	Os	Blue-white	190.8	22.477	.03113		
Palladium	Pd	White	106.5	11.4	.0582		
Platinum	Pt	White	194.5	21.5	.0314	8.042 Ag=100	37.9
Potassium	K	Silver-white	39.04	0.875	.166	11.23	45
Praseodymium	Pr		140.5		.0314		
Rhodium	Rh	Bluish-white	102.7	12.1	.05803		
Rubidium	Rb	White	85.2	1.52			
Ruthenium	Ru	White	101.4	12.261	.0611		
Samarium	Sm		150				
Scandium	Sc		44				
Silver	Ag	White	107.66	10.4-10.7	.0557	63.845	100
Sodium	Na	Silver-white	22.995	0.9735	.2734	18.3	36.5
Strontium	Sr	Ylwsh.-white	87.3	2.542			
Tantalum	Ta		183	10.8			
Tellurium	Te	White shining semimetal	127.49	6.255	.0475	.000777 Ag at 0° =1	
Terbium	Tr		160				
Thallium	Tl	White	203.64	11.88	.0325	5.225	
Thorium	Th	Greyish-white	232	11.1-11.23	.02787		
Tin	Sn	Silver-white	119	7.3	.0559	8.726	15.2
Titanium	Ti	Dark-grey	47.9	3.5888	.1135		
Tungsten	W	Steel-grey	184.4	18.77	.035		
Uranium	U	Silver-white	240	18.7	.0276		
Vanadium	V	Light-grey	51.4	5.5			
Ytterbium	Yb		173				
Yttrium	Y		89				
Zinc	Zn	Bluish-white	65.4	6.9-7.15	.0935	16.9	28.1
Zirconium	Zr	Grey	90.5	4.15	.066		

*Also called beryllium †Also called columbium

CONTRACTION OF METALS IN COOLING

Metal	In fractions of linear dimensions	In parts of an inch per foot of linear dimensions
Cast iron	$\frac{1}{96}$	$\frac{1}{8}$
Gun metal	$\frac{1}{72}$	$\frac{1}{6}$
Yellow brass	$\frac{1}{64}$	$\frac{3}{16}$
Copper	$\frac{1}{60}$	$\frac{1}{5}$
Zinc and tin	$\frac{1}{48}$	$\frac{1}{4}$
Lead	$\frac{1}{39}$	$\frac{5}{16}$

CONTRACTION OF CASTINGS

		Inch
Thin brass	=	$\frac{1}{8}$ in 9 inches
Thick brass	=	$\frac{1}{8}$ in 10 inches
Gunmetal rods	=	$\frac{1}{8}$ in 9 inches
Zinc	=	$\frac{5}{16}$ per foot
Copper	=	$\frac{3}{16}$ per foot
Bismuth	=	$\frac{5}{32}$ per foot
Tin and lead, each	=	$\frac{1}{4}$ per foot
Aluminum	=	$\frac{17}{64}$ per foot
Delta metal	=	$\frac{3}{16}$ per foot
Manganese bronze	=	$\frac{1}{4}$ per foot

When a substance $\left\{\begin{matrix}\text{expands}\\ \text{contracts}\end{matrix}\right\}$ in the act of fusion, the solid parts will $\left\{\begin{matrix}\text{sink}\\ \text{rise}\end{matrix}\right\}$ in the liquid. Such substances have their temperature of fusion $\left\{\begin{matrix}\text{raised}\\ \text{lowered}\end{matrix}\right\}$ while under pressure. Example: $\left\{\begin{matrix}\text{cast iron}\\ \text{water}\end{matrix}\right\}$.

For a rise of 10 degrees Fahrenheit (5.5 degrees Centigrade)—

Iron expands about	$\frac{1}{15000}$
Steel expands about	$\frac{1}{17000}$
Copper expands about	$\frac{1}{10500}$
Brass expands about	$\frac{1}{9500}$

TABLE OF SPECIFIC GRAVITY, WEIGHT PER CUBIC INCH, SPECIFIC HEAT, LATENT HEAT OF FUSION, AND APPROXIMATE MELTING POINTS OF METALS

Name	Specific gravity	Grams per cubic inch	Specific heat	Latent heat of fusion	Melting point Cent.	Authority for melting points
Aluminum	2.6	42.62	.222	80	625	Roberts-Austin
Antimony	6.8	111.48	.051	16	432	Pouillet
Bismuth	9.8	160.66	.031	12.4	268.3	Rudberg
Cadmium	8.66	141.97	.055	13.1	320.7	Person
Chromium	6.65	109.02	.100	....	1515	E. A. Lewis
Cobalt	8.7	142.62	.107	68	1500	Pictet
Copper	8.9	145.90	.095	43	1054	Violle
Gold	19.33	316.89	.032	16.3	1045	Violle
Iridium	22.42	367.55	.033	28	1950	Violle
Iron, wrought	7.8	127.87	.112	69	1600	Pictet
Lead	11.35	186.07	.032	5.4	326.2	Person
Magnesium	1.71	28.03	.245	58	750	
Manganese	7.39	121.15	.122	....	1245	Heraeus
Mercury	13.59	222.79	.032	2.8	—39.5	Regnault
Nickel	8.6	140.98	.108	68	1484	Bredig
Osmium	22.47	368.37	.031	35	2500	Pictet
Palladium	11.4	186.89	.059	36.3	1587	Bredig
Platinum	21.5	352.47	.032	27.2	1780	Bredig
Rhodium	12.10	198.37	.058	52	2000	Pictet
Ruthenium	12.26	200.99	.061	46	2000+	Deville & Debray
Silver	10.53	172.62	.057	24.7	961.5	Bredig
Tin	7.3	119.67	.056	14.5	232.7	Person
Titanium	3.58	58.69	.113	....	3000	
Tungsten	18.77	307.71	.035	....	1700	
Zinc	6.9	113.12	.096	22.6	419	Bredig

TABLE SHOWING METALS IN ORDER OF MALLEABILITY, DUCTILITY AND TENACITY

Malleability	Ductility	Tenacity
Gold	Gold	Iron
Silver	Platinum	Copper
Aluminum	Silver	Platinum
Copper	Aluminum	Silver
Tin	Iron	Aluminum
Platinum	Copper	Gold
Lead	Zinc	Zinc
Iron	Tin	Tin
Zinc	Lead	Lead

TABLE OF THE WEIGHT, IN POUNDS, PER FOOT IN LENGTH OF GUN METAL.

Composition: Copper, 9 parts; Tin, 1 part

Side of the square or diameter	Square	Hexagon	Octagon	Circle
½	.875	.756	,728	.686
¾	1.967	1.711	1.648	1.554
1	3.500	3.027	2.915	2.747
1¼	5.467	4.732	4.553	4.294
1½	7.875	6.814	6.559	6.184
1¾	10.717	9.275	8.928	8.417
2	14.000	12.113	11.662	10.993
2¼	16.717	15.333	14.749	12.916
2½	21.875	18.928	18.207	17.178
2¾	26.467	22,904	22.032	20.786
3	31.500	27.261	26.222	24.738
3¼	36.967	31.993	30.772	29.034
3½	42.875	37.107	35.693	34.273
3¾	49.217	42.605	40.971	38.654
4	56.000	48.464	46.616	43.981
4¼	63.217	54.715	52.629	49.651
4½	70.875	61.341	59.003	55.664
4¾	78.967	68.344	65.740	62.020
5	87.500	75.729	72.845	68.722
5¼	96.467	83.492	80.307	75.764
5½	105.875	91.633	88.140	83.153
5¾	115.717	100.152	96.337	90.884
6	126.000	109.053	104.895	98.959
6¼	136.717	118.328	113.816	107.376
6½	147.875	127.984	123.111	116.140
6¾	159.467	138.019	132.758	125.244
7	171.500	148.431	142.775	134.694
7¼	183.967	159.222	153.153	144.487
7½	196.875	170.394	163.898	154.623
7¾	210.217	181.744	175.010	165.105
8	224.000	193.872	186.483	175.927
8¼	238.217	206.178	198.320	187.096
8½	252.875	218.862	210.541	198.607
8¾	267.967	231.927	223.090	210.462
9	283.500	245.367	236.019	222.659
9¼	299.467	259.189	249.312	235.200
9½	315.875	273.392	262.969	248.087
9¾	332.717	287.969	276.993	261.317
10	350.000	302.928	291.382	274.890
10¼	367.717	318.258	306.131	288.802
10½	385.875	333.977	321.247	303.065
10¾	402.467	350.066	336.724	317.667
11	423.500	366.541	352.572	332.615
11¼	442.968	383.393	368.781	347.907
11½	462.875	400.617	385.350	363.538
11¾	483.217	418.124	402.290	379.519
12	504.000	436.212	419.587	395.839

The following table gives the weights of most ordinary metals and alloys:

Metal	Weight per cubic inch, pounds	Weight in pounds per cubic foot	Weight of 1 square foot, 1 inch thick, in pounds
Copper	.318	549	46
Nickel	.318	518	45
Zinc	.248	429	37½
Aluminum	.093	160	14
Lead	.410	710	60
Antimony	.242	420	35
Tin	.264	456	38
Gun metal	.315	544	44½
Brass	.3	520	43
Magnolia	.376	650	54

The lightness of aluminum is best illustrated by the following table, comparing it with other metals.*

	Specific gravity	Weight per cubic ft. pounds	Volume per lb. weight in cubic feet	Relative Spec. Gr. A1=1
Aluminum	2.56	160	0.00625	1.000
Antimony	6.72	420	0.00238	2.625
Zinc	7	437	0.00229	2.734
Iron	7.23	451	0.00222	2.824
Tin	7.29	455	0.00220	2.848
Steel	8	499	0.00200	3.125
Copper	8.6	537	0.00186	3.859
Bismuth	9.82	613	0.00163	3.836
Silver	10.47	654	0.00153	4.090
Lead	11.36	709	0.00141	4.438
Mercury	13.60	849	0.00118	5.312
Gold	18.41	1150	0.00087	7.191
Platinum	21.53	1344	0.00074	8.410

TABLE SHOWING THE ALLOYS WHOSE DENSITY IS GREATER (+) OR LESS (—) THAN THE MEAN OF THEIR CONSTITUENTS

+ Alloys	— Alloys
Gold and zinc	Gold and silver
Gold and tin	Gold and iron
Gold and bismuth	Gold and lead
Gold and cobalt	Gold and copper
Gold and antimony	Gold and iridium
Silver and zinc	Gold and nickel
Silver and bismuth	Silver and copper
Silver and antimony	Iron and bismuth
Copper and zinc	Iron and antimony
Copper and tin	Iron and lead
Copper and lead	Tin and lead
Copper and bismuth	Tin and antimony
Lead and antimony	Nickel and arsenic
Platinum and molybdenum	Zinc and antimony

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*Glucinum is lighter than aluminum and equally durable, a better conductor of electricity than copper or even silver, and stronger than iron. Only the expense of production prevents this metal proving of great industrial value.

PROPERTIES OF ALLOYS

Alloys	Specific gravity	Weight of a cubic foot in pounds	Tenacity in pounds per square inch	Crushing force in pounds per square inch	Melting point, degrees Fahr.
Aluminum bronze (5% Al)	7.68	480	71,680	.....	1900
Brass (tube) (67:33)	8.43	526	26,600	.....	—
Brass (cast) (2:1)	8.4	525	17,978	10,300	1800
Naval brass (rod)	....	....	60,480	.....	1832
Muntz metal (rolled)	8.405	524	62,720	.....	—
Delta metal (rolled)	8.45	527	91,800	.....	1850
Gun metal (88:12)	8.56	534	36,500	.....	1900
Phosphor bronze	8.60	536.8	38,208	.....	1800
Steel (average)	7.85	489.5	120,000	.....	3250
Iron (No. 3 Pig)	7.126	444.6	21,859	91,661	—
Iron (No. 1 Pig) (cold blast)	7.137	446	23,257	95,775	—
Aluminum brass (2% Al)	8.33	....	70,000	.....	—
Babbitt's alloy	7.5	450	9,000	16,000	440

Dr. J. Ure's rule for calculating the specific gravity of an alloy:

$$M = \frac{(W-w)\,Pp}{Pw + pW}$$

M is the mean specific gravity of the alloy, W and w the weights, and P and p the specific gravities of the constituent metals.

TO FIND THE WEIGHT OF A CASTING FROM THAT OF THE PATTERN

A pattern weighing one pound	Will Weigh When Cast In					
	Cast iron	Yellow brass	Gun metal	Zinc	Copper	Aluminum
Bay wood	8.8	9.9	10.3	8.5	10.5	3.2
Beech	8.5	9.5	10.	8.2	10.1	3.1
Cedar	16.1	18.	18.9	15.6	19.2	5.8
Cherry	10.7	12.	12.6	10.4	12.8	3.9
Linden	12.	13.5	14.1	11.6	14.3	4.3
Mahogany	8.5	9.5	10.	8.2	10.1	3.1
Maple	9.2	10.3	10.8	8.9	11.	3.2
Oak	9.4	10.5	11.	9.1	11.2	3.4
Pear	10.9	12.2	12.8	10.6	13.	3.9
Pine, white	14.7	16.5	17.3	14.3	17.5	5.3
Pine, yellow	13.1	14.7	15.4	12.7	15.6	4.7
Whitewood	16.4	18.4	19.3	15.9	19.5	5.9

Allowance must be made for the metal in the pattern.

Reduction for Round Cores and Core Prints

Rule.—Multiply the square of the diameter by the length of the core and prints in inches, and the product by 0.014. This will give the weight of the white pine core, to be deducted from the weight of the pattern.

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